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VOL. 42 NO. 389 MAY 1956

THE INSTITUTE OF PETROLEUM

AN Ordinary General Meeting of the Institute of Petroleum was held at 26 Portland Place, London, W.1, on 11 January 1956, the chair being taken by Lt-Col. S. J. M. Auld, O.B.E., M.C., D.Sc., President of the Institute.

The General Secretary read the minutes of the meeting held on 14 December 1955, which were confirmed and signed as a correct record. He also announced the names of members elected since the previous meeting.

The Chairman then introduced D. G. Tompkins and G. F. J. Murray, who presented the following paper in summary:

PETROLEUM FUELS FOR DOMESTIC HEATING AND LIGHTING*

By D. G. TOMPKINS† (Fellow) and G. F. J. MURRAY† (Associate Fellow)

PART I

THE market and application of the various forms of petroleum for domestic use fall naturally into several classes. These are, in simple terms:

(*a*) paraffin and other petroleum waxes;
(*b*) the petroleum gases making up commercial propane and butane;
(*c*) light petroleum products similar to motor spirit and of low flash point;
(*d*) kerosine;
(*e*) gas oil and domestic fuel oil.

PARAFFIN WAX

This, although a typical petroleum product, had appeared on the market ahead of the petroleum industry proper, being made from Scottish shale oil and exhibited by Young at the Great Exhibition of 1851.

In 1855 Price's Patent Candle Company of Battersea made wax for candles by the distillation of Burmese petroleum in superheated steam, and this proved to be a much cheaper source than natural waxes and fatty acids.

The two products of the candle trade are the candle and the nightlight, the essential difference between the two being the time of burning and the amount of molten wax at the base of the flame.

LIQUEFIED PETROLEUM GASES (LPG)

These are the product of refinery operations and can be liquefied by moderate pressures for transportation and distribution. They are readily vaporized and used in a very wide range of domestic equipment.

Butane is the gas most commonly used in a wide variety of domestic applications.

About 50,000 tons of butane and 8000 tons of propane were distributed in the U.K. in 1954. In general, butane goes largely to the domestic field and propane to industry.

The British Standards Institution is drawing up specifications for propane, butane, and for various appliances using these gases. BS 2491 Part I (covering appliances for use with butane gas) has been issued.

The properties of commercial butane are given in Table I.

Since commercial butane may be relatively free from smell, odorants are now incorporated to give a distinctive smell at a gas concentration in air of one-fifth of the lower explosive limit.

TABLE I

Sp. gr. of liquid at 60° F	0·56–0·57
Sp. gr. of gas at 60° F and 30 inch Hg (air = 1)	1·9–2·1
Boiling point of liquid at atmospheric pressure	30° F
Calorific value (gross), B.t.u/lb	21,300
Total sulphur content, % wt	less than 0·01
Cu. ft. of gas per lb	6·7
Limits of inflammability (% vol of gas in air to produce explosive mixture)	1·5–8·5

As a domestic fuel butane possesses advantages. It is of constant quality, extremely convenient, clean, non-toxic, and the products of combustion are free from deleterious substances when it is burned correctly. The high calorific value permits the use of relatively small bore tubing for distribution and allows neat, compact piping arrangements.

The butane cylinder, as supplied by the distributor, has a specially designed valve to enable the contents to be withdrawn as desired. Since the pressure in the cylinder is of the order of 30 p.s.i. at 60° F and must be reduced to between 12 and 14 inches of water gauge before reaching the appliance, a pressure regulator is fitted to maintain a reliably constant pressure in the pipes under varying take-off rates until the cylinder pressure becomes too low. For domestic installations, evaporation takes place in the vessel. Heat to supply the latent heat of vaporization is therefore taken from the cylinder and the remaining liquid.

* MS received 29 December 1955.

† The British Petroleum Co. Ltd.

When correctly installed the supply is free of mains fluctuations which can occur at peak load periods. The cost of distribution is, however, necessarily high due to the large investment and maintenance associated with the sale of a product in what is really a portable pressure vessel.

The following values give a comparison with other forms of domestic energy :

1 lb of butane is equivalent to 6·15 kW-hr or approximately 47 cu. ft. of town's gas.
1 therm (100,000 B.t.u.) is equivalent to 4·76 lb of butane.
1 gal of kerosine is equivalent to about 7·5 lb of butane.

LIGHT PETROLEUM PRODUCTS

In the U.K. and many other countries, motor spirit, though bearing a relatively low distribution cost, can-

FIG 1
CATALYTIC STOVE

not compete with kerosine and butane for domestic purposes, mainly because taxation makes it uneconomical. In countries where taxation permits, light petroleum products are used for domestic heating and an appliance commonly used in France is the catalytic stove (Fig 1).

The fuel specified for the stove is a lead-free straight-run hydrocarbon oil of 70°–100° C boiling range. Heavier products tend to accumulate in the catalyst and interfere with its operation. The appliance is suitable only for space heating, since the products of combustion are relatively cool (about 300° C) and therefore not usable to ensure efficient and rapid heat-transfer to another medium as is called for in cooking.

The platinized asbestos catalyst plate is preheated by methylated spirit or by electricity until hot enough for surface combustion to be self-supporting. Once started, it will burn continuously until the reservoir is empty. To shut off, a cover is put on to exclude air.

KEROSINE

Between about 1860 and 1910 kerosine was the most important product of the trade, and in 1879 for instance, represented 55 per cent of petroleum sales in North America and 72 per cent of the value. During this period the products distilling on each side of the kerosine were in less demand and commanded lower prices. This encouraged refiners to make a wide cut to increase the availability of burning oil, and the flash point was thus often brought down to a dangerous level. The inclusion of higher boiling fractions must also have led to an abnormal amount of servicing to lamps owing to char and carbon formation on wicks. The kerosines of 100 years ago had flash points much lower than those of the fatty oils they were superseding, but in 1879 the Petroleum Act laid down a minimum Abel flash point of 73° F for kerosine. At the present time, safety considerations and changes in utilization of petroleum products have raised the flash points of modern burning oils in the U.K. to 100° F or over.

Various aspects of kerosine quality influence its suitability as a domestic fuel, *e.g.* heat output rating of a heater or cooker is largely controlled by the smoke point; the higher this value, the more fuel can be burnt in a given time without the development of smoke. The char value assesses the tendency of a kerosine to form a carbonaceous crust on the wick tip of a wick fed appliance. This crust impedes the flow of fuel up the wick, causes uneven burning and bad odour of the products of combustion. Char development is a function of the degree of refining of a burning oil, of contamination during distribution, and the design of the appliance. The addition of 0·01 per cent by weight of brightstock or 1 per cent of gas oil raises the char value of a premium kerosine by about 10 mg.

The IP has standardized a number of tests specifically for the measurement of kerosine quality. These are essentially practical tests where performance is concerned and include the smoke point and char value estimations. The char developed by various appliances is not necessarily in line with the value found by IP procedure, some giving less char, others more.

KEROSINE BURNING APPLIANCES

A great deal of research has gone into the development of appliances for domestic use. Lighting and heating equipment of high quality and performance is available for most household purposes where safety and efficiency are of the greatest importance. BS 2049 is intended to cover these aspects :

BS 2049 Kerosine (paraffin) appliances for domestic use.
Part I. Burners, portable space heaters, cooking and boiling appliances.
Part II. Lighting appliances.

TYPES OF DOMESTIC HEATERS

The majority of kerosine heaters are free-standing, portable, flueless appliances. They are classified by fundamental design, *e.g.* long-drum, short-drum, or pressure type, or by functions such as cooker, convector heater, etc.

Burners are capable of classification by subdivision into :

(*a*) Long-drum burners—
(i) white flame type;
(ii) blue flame type;
(iii) flat wick type.

(*b*) Short-drum burners—
(i) wick fed type;
(ii) kindler type.

(*c*) Pressure burners.

Each of these basic burner designs has its place according to the service demanded. See Figs 2–9.

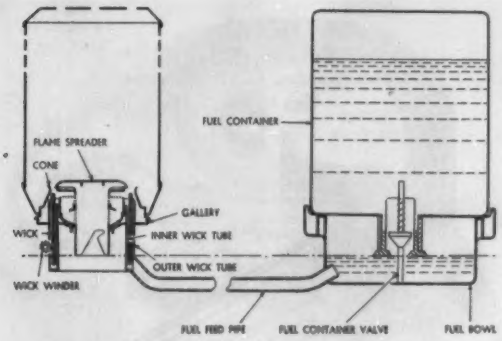


FIG 2
LONG-DRUM BURNER
From BS 2049, Pt. I

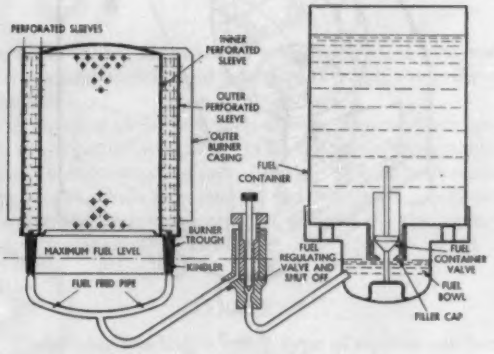


FIG 3
SHORT-DRUM BURNER : KINDLER TYPE
From BS 2049, Pt. I

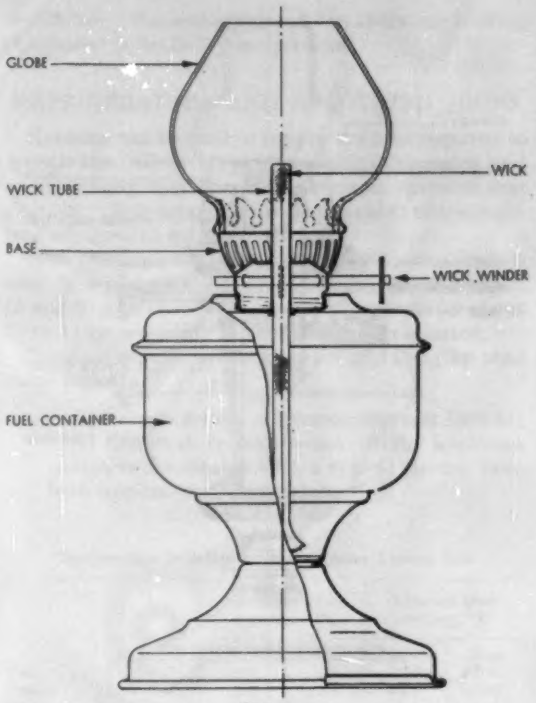


FIG 4
TYPICAL SOLID ROUND WICK LAMP
From BS 2049, Pt. II

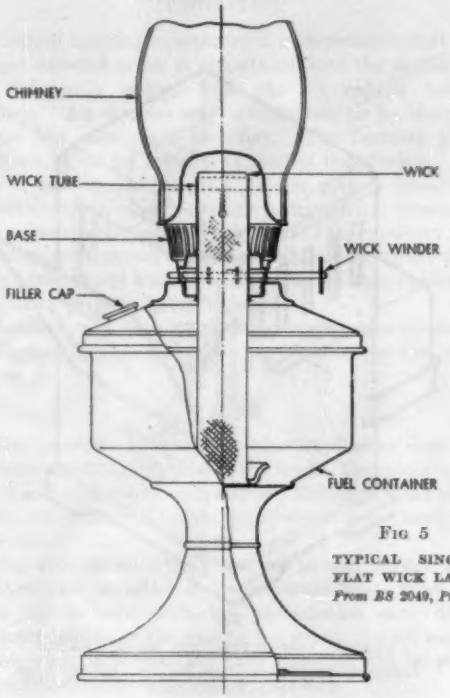


FIG 5
TYPICAL SINGLE FLAT WICK LAMP
From BS 2049, Pt. II

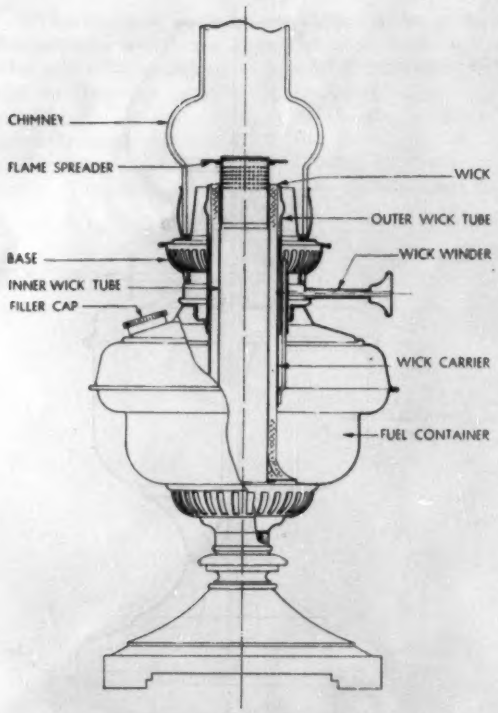


FIG 6

TYPICAL CIRCULAR WICK LAMP (CENTRE DRAUGHT)

From BS 2049, Pt. II

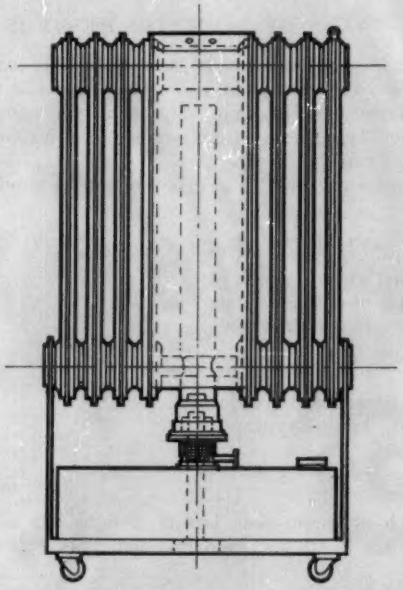


FIG 8

RADIATOR-TYPE SPACE HEATER

Incorporating long-drum burner

From BS 2049, Pt. I

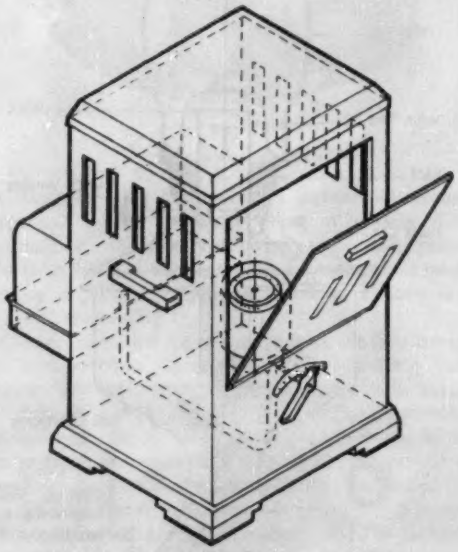


FIG 7

CABINET CONVECTOR-TYPE SPACE HEATER

Incorporating short-drum burner: kindler type

From BS 2049, Pt. I

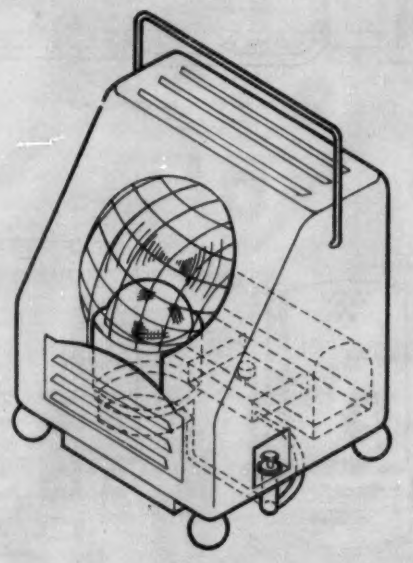


FIG 9

RADIANT-TYPE SPACE HEATER

Incorporating short-drum burner: kindler type

From BS 2049, Pt. I

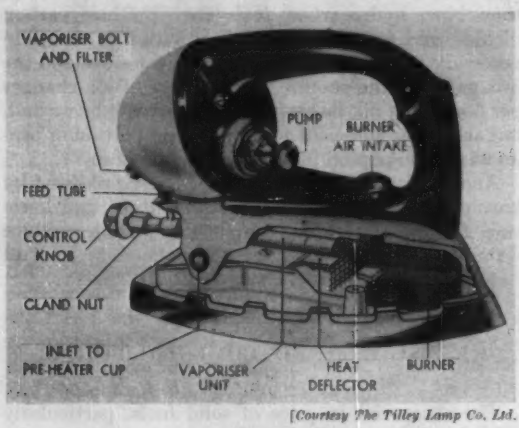
PERFORMANCE

The performance of an appliance is associated with many factors, foremost of which is the nature of the products of combustion. Absence of smoke and odour in the home are very important and modern blue flame heaters operating on premier grade burning oil will work at exceptionally low odour and smoke levels. Since a kerosine heater burning without smoke ensures virtually complete combustion of the oil, the thermal output rating is calculated from the weight of fuel consumed at a calorific value of 18,750 B.t.u/lb (net), but it is valuable to state heat output in terms of kilowatts, since this is more easily understood by most purchasers of heaters.

FORMS OF SPACE HEATERS

These include the radiator type, convector heaters, and those giving a proportion of true radiant heat (Fig 9).

The present day convector heater is a cabinet stove in which air streams, within the steel box, cool the heating surface and pass out through the grille at the front.



[Courtesy The Tilley Lamp Co. Ltd.

FIG 10

DOMESTIC IRON

A number of heaters give a proportion of their heat in the form of radiation. The hot gases from a blue flame burner impinge on a dome or strip of heat resisting metal which is raised to red heat and a reflector directs the radiant energy in a beam at the correct angle for maximum comfort.

COOKERS

Under this heading is every type of equipment from the simple " Primus " type of pressure burner used as a boiling ring to elaborate three-burner cookers with an oven. The burner types are common to other appliances. An important point in operating cooking equipment is flexibility in operation.

REFRIGERATORS AND SMOOTHING IRONS

Kerosine can be used to supply the heat required to operate the " silent " type of domestic refrigerator, and an interesting appliance is the kerosine-operated iron (Fig 10). It is simple to use and capable of temperature adjustment for various fabrics.

This appliance has been found easy to start and to use. The fuel consumption can be controlled between 15 and 60 g/hr of kerosine, and it will operate for about 2½ to 11 hr according to the heat output selected.

Tests on regular grade kerosine of 14 mg/kg char value indicate :

(*a*) a vaporizer life of between 500 and 1000 hr;
(*b*) temperature distribution of the appliance compares favourably with a typical electric iron, both appliances being upright.

TABLE II

Temperature Distribution along Centre Line of Sole

	Kerosine iron setting, ° C		Electric iron setting, ° C	
	Min	Max	Min	Max
Toe . . .	130	170	100	135
Centre . . .	125	285	115	160
Heel . . .	100	185	105	140

LIGHTING

In all oil-burning equipment it is imperative that the correct amount of air is introduced into the appliance and efficiently mixed with the oil vapour before ignition. An obvious way is to induce air by the pull of the hot gases in a chimney. The familiar glass chimney, wick fed lamp is typical of this design.

The various simple wick lamps give a luminous yellow flame, the light emission coming from incandescent carbon particles. Work done at the Sunbury Research Station shows that a typical, well-designed wick lamp gives about 4 candle power for a consumption of 16 g/hr of premier grade kerosine.

Mantle lamps may be wick fed or pressure operated employing incandescent rare earth oxides as the light source.

WICKS

The operation of many kerosine appliances depends on the correct functioning of the wicks, the majority of which are still made from cotton, although some glass wicks are used. Kindler type wicks are usually of asbestos.

The wick must supply the oil to the burner at a uniform rate, to allow it to evaporate freely from the wick tip to mix with the combustion air. Since capillary action is the means by which the oil moves in the wick, it is essential that there should be minimum interference with this movement.

The wick should be dry and preferably dried immediately before inserting into the burner, since cotton takes up a great deal of water when in equilibrium with an atmosphere of high relative humidity. It is also important to make sure that water is not present in any oil reservoir. Due to the breathing of containers, moist air is drawn into them, and over a period of time liquid water may accumulate.

Investigations on the influence of moisture in wicks shows that its presence can produce marked changes in the burning of a lamp.

Table III gives the results of experimental work, carried out at the Sunbury Research Station, with wicks dried at 105° C to constant weight and wicks which have been allowed to come to equilibrium with water at room temperature.

TABLE III

Burning Test with IP Lamp showing Effect of Damp Wicks on Flame Height Drop

	High smoke point kerosine		Medium smoke point kerosine	
	Dry wick	Damp wick	Dry wick	Damp wick
Test No. 1:				
Lamp no.	1	2	1	2
% Drop in flame height at end of test	12·5	50	25	62·5
Consumption, g	452	378	511	384
Char value, mg/kg	1·1	1·3	5·2	5·0
Test No. 2:				
Lamp no.	2	1	2	1
% Drop in flame height at end of test	12·5	31·25	18·8	43·8
Consumption, g	448	405	500	450
Char value, mg/kg	1·6	1·7	5·8	5·5
Test No. 3:				
Lamp no.	1	2	1	2
% Drop in flame height at end of test	12·5	37·5	18·8	50·0
Consumption, g	470	420	500	415
Char value, mg/kg	0·6	1·2	5·6	5·0
Test No. 4:				
Lamp no.	2	1	2	1
% Drop in flame height at end of test	25	50	25	43·8
Consumption, g	475	445	477	434
Char value, mg/kg	1·1	1·2	5·2	5·0

These results indicate a marked drop in flame height with damp wicks and a fall in consumption to 87 per cent of that of the dry wicks. Char value is not affected. The consumption figures were measured over 24 hr, and at the end of that period (when the flame height was taken) the drop in consumption for the damp wicks was found to be considerable.

The presence of stiffeners and impregnants to give rigidity to wicks has been found to give greater quantities of char and to change its character. The char formed on stiffened wicks is hard and firmly bonded on to the cotton of the wick, making removal difficult.

Since there is a flow of oil up a wick, any suspended solids become filtered off into the textile, reducing the oil flow. Kerosine frequently contains finely divided rust from cans or from the reservoir of the appliance, and as the oil moves up the wick the part immersed in the fuel becomes stiff and dense with solids. Such a wick must be replaced.

VENTILATION

All the appliances for space heating are unflued and discharge their combustion products together with hot air into the room or space in which they operate. As most of the heat given off is in the form of hot air, losses would be considerable if flues were fitted.

Kerosine appliances produce very little carbon monoxide, in fact, the appliances smoke badly and tend to go out when deprived of sufficient air, which guards against the emission of this toxic gas. However, as they burn hydrocarbon fuels they produce carbon dioxide and water vapour. Ventilation is therefore necessary to ensure fresh air for both the stove and the occupants of the room. The number of air changes per hour must not be excessive, or heat will be wasted, but should be sufficient to keep the proportion of products of combustion in air at a low level.

Another factor is the amount of water produced by burning hydrocarbon fuels. Both butane and kerosine, for example, when completely burned, produce water to the extent of more than one-and-a-quarter times the weight of fuel consumed.

KEROSINE FIRED DOMESTIC BOILER UNITS

The sharp rise in price of solid fuels, particularly coke, has led to the design of conversion units for use in the smaller hot water or hot water–central heating boilers.

It is desirable that the minimum alterations are called for in making the conversion, and certain baffles may be needed as well as attention to the dampers. An important point is the avoidance of condensation in the stack-pipe or chimney, and some dilution of the stack gases may be necessary.

The ratings of these appliances tend to lie between 25,000 and 50,000 B.t.u/hr, and great ingenuity has been exercised in producing practical designs. Some incorporate thermostatic control of oil supplies, a low burning level or pilot flame permitting economical operation to be combined with correct thermal output.

PART II

This section deals with boilers of approx 20,000 B.t.u/hr for hot water supply, the larger central heating unit of 20,000–70,000 B.t.u/hr capacity and the large boiler up to 300,000 B.t.u/hr. Most of the liquid fuel installations are conversions from solid to liquid fuel firing.

Hot air systems used so commonly in the U.S.A. are the exception rather than the rule in the U.K., owing to the different methods of house construction. There are, however, a number of oil burner–boiler and hot air units now appearing on the U.K. market which follow present U.S. practice.

OIL BURNERS

The types of burners available for those combined units and for the conversion of existing solid fuel appliances can be classified as :

(1) the pot type vaporizing burner;
(2) the emulsion type;
(3) the fully automatic pressure jet burner.

THE POT TYPE VAPORIZING BURNER

This can be either (*a*) natural draught design or (*b*) assisted draught design.

(a) *Natural Draught Design*

Such burners are particularly susceptible both to variations in draught and to differences of quality of the fuel used. Incorrect installation and the use of an unsuitable fuel can lead to excessive carbon deposition on the burner, a high percentage of excess air, and consequent low thermal efficiency.

(b) *Assisted Draught Design*

To obtain more consistent results with less dependence on the variable natural draught from a domestic chimney the simple pot type burner has been modified by the addition of a small fan. This modification materially assists the air flow through the burner, supply air at a pressure of 0·05–0·08 inch of water only, the current consumption of the electric motor being small. Automatic control on the high–low flame principle can readily be incorporated, control being effected by means of a needle valve with or without variation of the fan speed for the different oil throughputs. An application to a domestic boiler is shown in Fig 11.

Typical test results on such a burner using gas oil are given in Table IV.

The coke formation on the burner was 23·3 p.p.m. over a period of 200 hr at a burning rate of 3·6 lb of oil per hr.

TABLE IV

Fuel consumption	CO_2 in products of combustion, %	Bacharach smoke no.
High flame :		
5 lb/hr . . .	14·6	5
4·15 lb/hr . .	12·0	—
3·6 lb/hr . . .	11·0	1
Low flame :		
0·25 lb/hr . . .	1·5	—

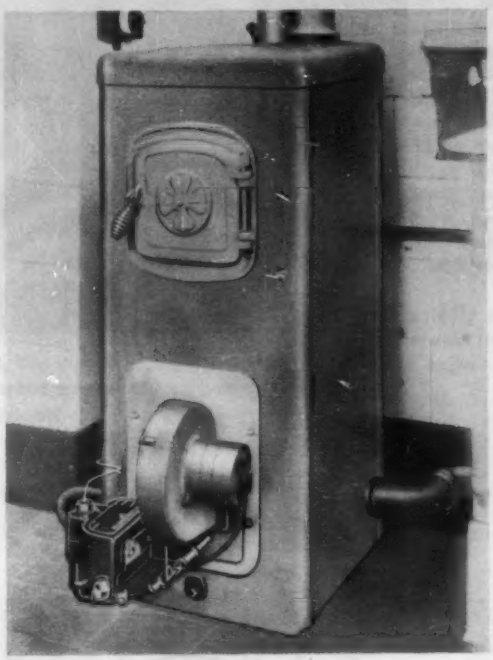
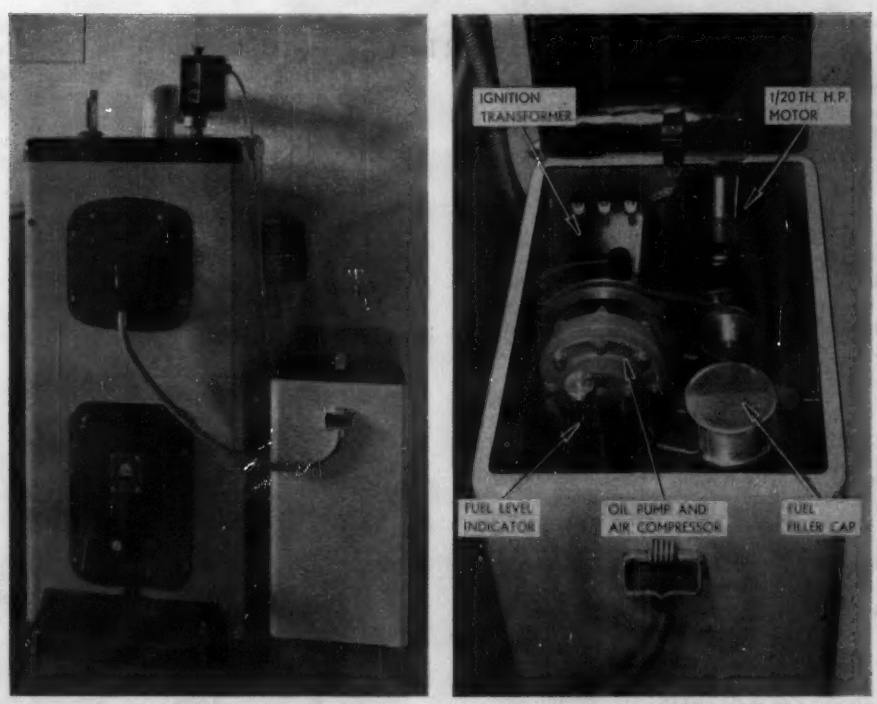


FIG 11
VAPORIZING BURNER APPLIED TO DOMESTIC BOILER

THE EMULSION TYPE OF BURNER

The other method frequently employed to burn fuel oil is that in which the fuel is injected into the combustion chamber in a finely divided state. This can readily be done in a fully automatic pressure jet type of burner but, in small boilers of up to 75,000 B.t.u/hr capacity, the nozzle must be extremely small and is subject to blockage. To avoid the necessity of using such small nozzles the emulsion type burner has been developed and a typical example is illustrated in Fig 12. These burners, which are completely automatic in operation, utilize the ON–OFF principle, ignition being by means of an electric spark across two electrodes.

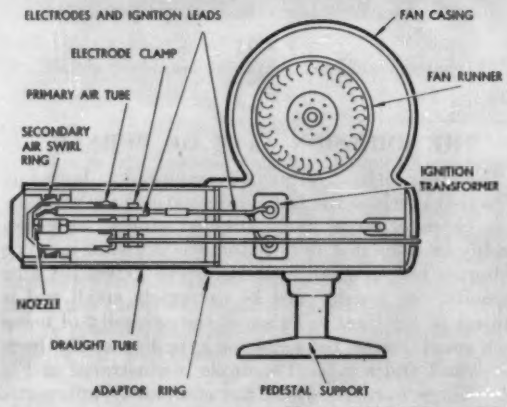


[*Courtesy British Oil Burners Ltd.*

FIG 12

BOILER FOR HOT WATER SYSTEM

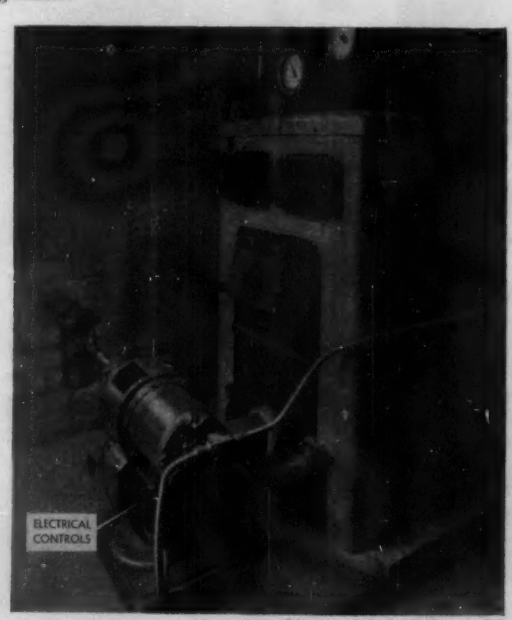
Emulsifying Burner



[*Courtesy British Oil Burners Ltd.*

FIG 13

FULLY AUTOMATIC PRESSURE JET BURNER



[*Courtesy British Oil Burners Ltd.*

FIG 14

FULLY AUTOMATIC PRESSURE JET BURNER APPLIED TO DOMESTIC BOILER

THE FULLY AUTOMATIC PRESSURE JET BURNER

This is the type most in use at the present time. The oil is supplied to a swirl type of nozzle, at pressures up to 150 p.s.i. from which it issues in a finely atomized condition. A forced draught air supply is provided round the nozzle and combustion takes place in the combustion chamber of the boiler. A typical example is illustrated in Fig 13, and Fig 14 shows the application to a boiler.

For larger boilers rated at 250,000 B.t.u/hr or higher the pressure jet burners can use successfully a 200 sec fuel which is preheated in order that it reaches the nozzle with the correct viscosity for good atomization.

The temperature range within which fuels should be preheated to ensure successful atomization is shown graphically in Fig 15.

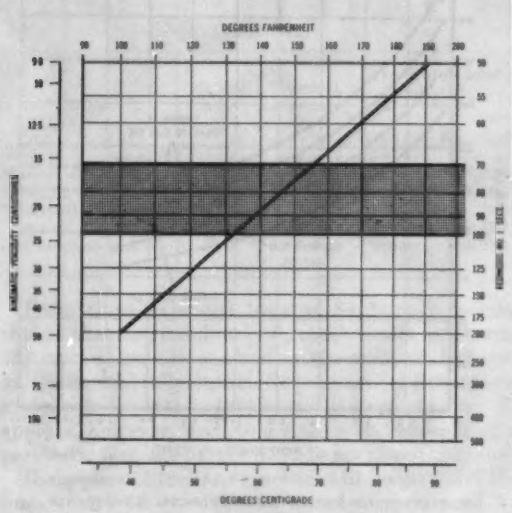


FIG 15

VISCOSITY LIMITS FOR GOOD ATOMIZATION

Fuel 200 sec Redwood I at 100° F

FUEL OILS FOR DOMESTIC BOILERS

THE FULLY AUTOMATIC PRESSURE JET AND EMULSION TYPES

In the U.K. the pressure jet fully automatic burners and others of similar type operate on gas oil, of which typical inspection figures are shown in Table V.

TABLE V

Gas Oil—Typical Inspection Analysis

Sp. gr. 60° F/60° F	0·83
I.B.P, ° C	183
F.B.P, ° C	346
Flash point, ° F	164
Sulphur, % wt	0·75
Viscosity, Redwood I at 100° F, sec	34
Carbon residue (Conradson) (10° residue), % wt	0·04
Calorific value (gross), B.t.u/lb	19,600

In France, owing to the fiscal regulations, a Fuel Oil Domestique is marketed (Table VI).

TABLE VI

Fuel Oil Domestique—Typical Inspection Analysis

Sp. gr., 60° F/60° F	0·87
I.B.P, ° C	188
F.B.P, ° C	369
Flash point, ° F	140
Sulphur, % wt	1·40
Viscosity Redwood I at 100° F, sec	40
Carbon residue (Conradson), % wt	0·63
Calorific value (gross), B.t.u/lb	19,500

This fuel may contain up to 10 per cent residue, and with it satisfactory operation of burners of the pulverization type is possible. Extended tests on burners show that, in a well designed appliance, *i.e.* one with good cut-off valves, correct air mixing, and, in certain cases, nozzle shielding, the Conradson carbon number of the oil has little influence on their operation. If adequate attention is not paid to these points the burner may be subject to nozzle carbon build up and the combustion chamber may be dirty. To minimize these effects it is sometimes the practice to state that only oils of low Conradson carbon values shall be used. Such a limitation may reduce the rate of carbon build up, but the fault, more often than not, lies with the burner, not with the fuel itself.

The output of a burner nozzle varies directly as the square root of the fuel pressure. It is also affected by the viscosity and density of the oil. The approximate throughput can be expressed as

$$Q = AC\sqrt{\frac{2gP}{\rho}}$$

where Q = throughput of burner nozzle;
A = area of nozzle outlet;
C = nozzle discharge coefficient;
P = pressure behind nozzle;
ρ = density of oil;
g = acceleration due to gravity.

Nozzle characteristics also affect throughput, and for the purpose of the graphical representation shown in Fig 22 a flow number of 1 relates to kerosine as the fuel. This serves to show the variations which can be expected. An evenly atomized oil spray is essential for efficient operation, and therefore nozzle characteristics are of paramount importance.

Both high gravity and high viscosity give a high throughput in the range of fuels considered in the present paper, and therefore oils combining high values of these two properties can give difficulties with some burners, the high throughput usually causing flame instability and poor combustion. These difficulties can be overcome by directing an adequate amount of air from the draught tube into the spray, provided the air flow is properly controlled, and at sufficiently high pressure. Pressures as high as 0·5 inch w.g. are employed in the draught tube of some of the most successful of this type of burner.

To meet the conditions arising in the U.S.A. when blended heating oils containing cracked components were marketed, so-called combustion heads were

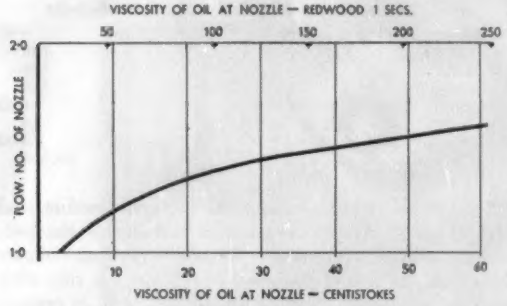


FIG 16

VARIATION OF OIL THROUGHPUT OF A NOZZLE WITH VISCOSITY OF OIL

designed for this class of burner. In this way, although higher air pressures are required for directing the air into the atomized oil spray, the difficulties of flame instability, high smoke level, and uneven combustion have been overcome.

A typical combustion head is shown in Fig 17.

As thousands of the usual pressure jet type of burner are in use without combustion heads, it was necessary to determine how they would operate on cracked fuels and blends of gas oil and residual fuels, in place of the normal straight run gas oils in common use when the burners were first designed.

Tests were therefore carried out at the Sunbury Research Station on a typical pressure jet automatic burner to determine the effect of variations in oil

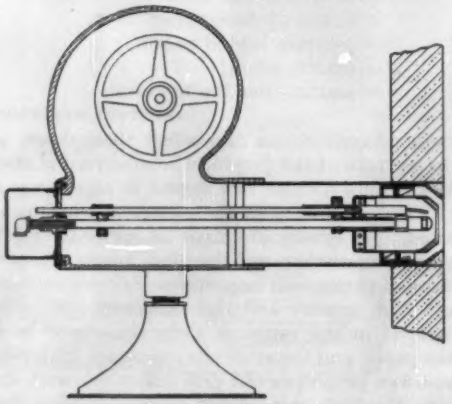


FIG 17

COMBUSTION HEAD FITTED TO TYPICAL BURNER INSTALLED IN REFRACTORY COMBUSTION CHAMBER

qualities. The burner was used in conjunction with a typical C.I. sectional type heating boiler.

Curves of smoke density related to excess air were obtained for the following fuels: straight run gas oil; marine diesel oil; catalytically cracked gas oil; thermally cracked gas oil.

The results are represented graphically in Fig 18. Examination of the curves shows that:

(*a*) For the same smoke density cracked oils require higher excess air figures.

(*b*) That a marine diesel oil can be burnt at a lower excess air figure than a straight run gas oil for the same smoke number.

Another way in which the performance of different fuels can be assessed is to measure the amount of soot deposited on the secondary heating surfaces of the boiler. In these tests the plant was operated under two sets of conditions, representing winter and summer,

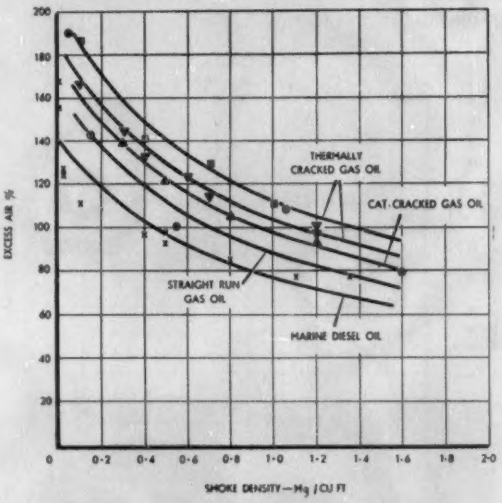


FIG 18

VARIATION OF SMOKE DENSITY WITH EXCESS AIR

at similar smoke levels when the burner was operating. For "winter" operation the burner was "on" for 24 minutes and "off" for 6 minutes, while "summer" conditions were "on" for 5 minutes and "off" for 15 minutes. The deposits were collected on a plate placed in the gas-ways in the boiler.

TABLE VII

Soot Deposits on Boiler Heating Surfaces

Fuel type	C–H ratios	Deposits/Gal of fuel			
		Summer operation		Winter operation	
		mg/sq. ft.	cc/sq. ft.	mg/sq. ft.	cc/sq. ft.
Straight run gas oil	6·4	60	1·5	42	1·5
Thermally cracked gas oil	6·9	92	2·7	63	1·7
Cat cracked gas oil	7·6	69	1·9	72	2·1

Table VII shows the results obtained, and the figures are related to the same smoke density in the flue gases.

From Table VII it can be seen that the cracked fuels give a higher weight of carbon lay-down on the boiler surfaces. The second column under the deposit section gives the volume of carbon deposited, and it will be seen that the carbon from the cracked oil is less dense.

While it is certain that carbon build up on the secondary heating surface of a boiler will lead to a reduction in thermal efficiency, extended tests have, so far, failed to reveal any correlation between the amount deposited and the reduction obtained.

The figures obtained vary between 0·5 and 1·0 per cent reduction in efficiency per gram of carbon deposited per square foot of heating surface on the boiler under test.

The thermal efficiencies and heat outputs obtained for the same smoke levels, 6 mg of soot per cu. ft., on this boiler are given in Table VIII.

TABLE VIII

Fuel	Excess air, %	Thermal efficiency, %	Computed heat output	
			B.t.u/lb	B.t.u/gal
Marine diesel oil	92	70	13,550	115,070
Straight run gas oil	106	68·5	13,360	111,600
Thermally cracked gas oil	123	67	12,940	110,490
Cat cracked gas oil	116	67·5	12,650	114,030

From these extended tests at Sunbury it is concluded that marine diesel oil, catalytically or thermally cracked gas oils, or blends of these oils can be burnt on the normal fully automatic pressure jet burner in a manner just as satisfactory as straight run gas oils. It appears, however, that, to get the best results from a particular fuel, the burner must be set to suit that fuel.

If supplies of fuel are consistent in quality and the fuels are stable no difficulty will be experienced by consumers in their operation. It is also considered that the fitting of combustion heads will give higher thermal efficiencies owing to the higher CO_2 figures obtainable at the same smoke level when burning any of the fuels mentioned.

For the fully automatic burner of the so-called heavy fuel type a suitable oil has a typical analysis as follows :

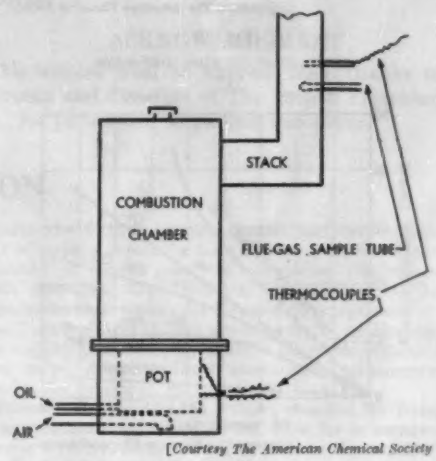
Sp. gr. 60° F/60° F	0·92
Flash point, ° F	202
Viscosity Redwood I at 100° F, sec	197
Calorific value (gross), B.t.u/lb	18,700
Ash content, % wt	0·016

Oils such as this must be preheated to a temperature so that the viscosity at the burner nozzle is correct, and if this be done there are no difficulties arising from fuel oil quality. From some isolated experiences in the field, evidence is available which indicates that the distillation range is of some importance in securing flame stability and smokeless combustion. More work on the effects of variation in distillation range on these factors is required.

THE POT TYPE VAPORIZING BURNER

In this clase of burner the fuel is vaporized and the vapour–air mixture burns over the pot. Heat radiated and conducted from the flame vaporizes the fuel. These burners are particularly susceptible to draught conditions, and for this reason the assisted draught type (Fig 11) gives more satisfactory operating results. When properly installed in well-sealed boilers very good results can be obtained.

So far as quality is concerned the fuel required is that giving the least carbon deposition in the pot of the burner. From experience, kerosine is the preferred fuel but there are now many thousands of these burners operating on gas oil; in fact, this fuel is often recommended by the burner manufacturers.



[*Courtesy The American Chemical Society*

FIG 19

STANDARD POT BURNER

As the natural draught pot burner subjects the fuel to very severe operating conditions it is usual to use it for evaluation purposes, and the Standard Oil Company of Indiana have designed one which burns 2·5 gal of oil in 20 hr. The general arrangement of the test equipment is shown in Fig 19.

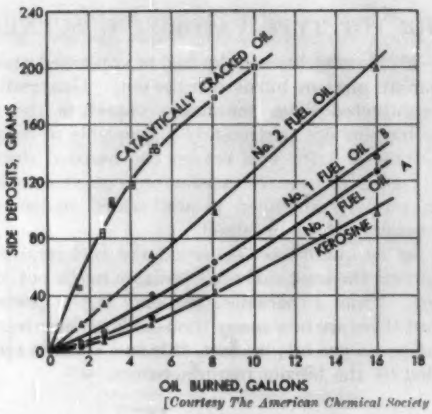
TABLE IX

Properties of Laboratory Test Fuels

	Kerosine	No. 1 oils		No. 2 oil	Catalytically cracked oil
		A	B		
Sp. gr. 60° F/60° F	0·8091	0·8146	0·8146	0·8393	0·8714
ASTM distillation, ° F :					
I.B.P.	356	334	320	330	383
10%	380	376	356	376	419
50%	427	442	415	470	461
90%	474	522	510	585	516
F.B.P.	520	566	568	655	596
Sulphur, % wt	0·10	0·12	0·33	0·64	1·04

Tests were carried out on five different fuels, the characteristics of which are shown in Table IX.

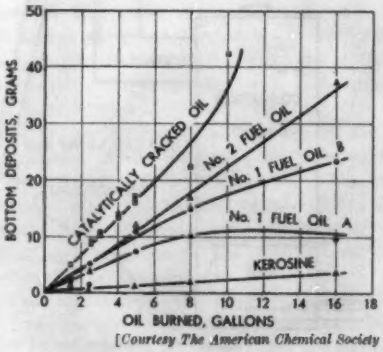
From the results of these tests the quantities of side and bottom deposits in the burner are shown graphic-



[Courtesy The American Chemical Society

FIG 20

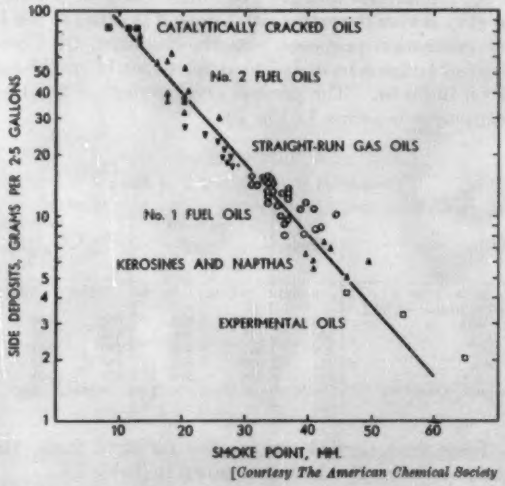
FORMATION OF SIDE DEPOSITS



[Courtesy The American Chemical Society

FIG 21

FORMATION OF BOTTOM DEPOSITS



[Courtesy The American Chemical Society

FIG 22

CORRELATION OF SMOKE POINT WITH SIDE DEPOSITS

ally in Figs 20 and 21. The amount of side deposit can be related to fuel consumption and, in general, the oil containing the higher proportion of cyclic and aromatic hydrocarbons gives rise to the highest quantity of deposit. The relationship between the smoke point of the fuel and the amount of deposit on the side of the burner is admirably shown in Fig 22. In this connexion the smoke point test has been used over a wider range of fuels than that for which it was designed, but even so, the graph shows that there is correlation.

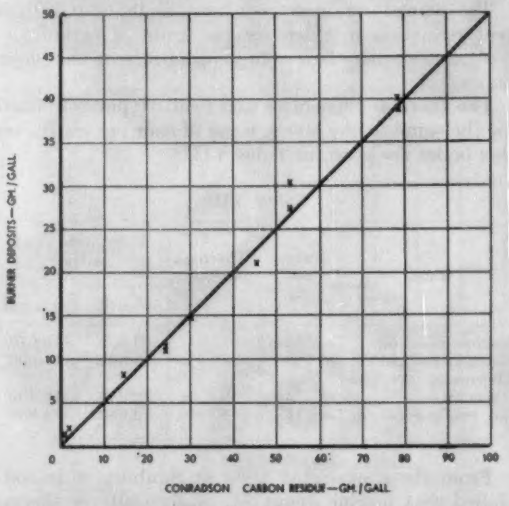


FIG 23

DEPOSIT FORMATION IN NATURAL DRAUGHT POT BURNER
EFFECT OF CONRADSON CARBON RESIDUE ON DEPOSITS

In some parts of the world a domestic fuel oil is marketed consisting of gas oil containing a proportion of residue. A number of tests were carried out with such a fuel at the Sunbury Research Station, on a natural draught burner, with the results shown in Table X.

TABLE X

Pot Burner Tests—Relationship between Conradson Carbon and Coke Deposits

	Conradson carbon		Burner deposit, g/gal
	% wt	g/gal	
Straight run gas oil . .	0·005	0·2	1·0
Thermally cracked gas oil .	0·03	1·2	1·8
95% S.R.G.O. + 5% Res..	0·038	14·4	8·33
Domestic fuel oil (A) .	0·80	30·5	14·8
Domestic fuel oil (B) .	1·15	45·7	21·0

From the results plotted in Fig 23 it can be seen that there is a linear relationship between the Conradson carbon of the oil and the burner deposits.

. The tests were continued until the burner failed to operate at a fixed smoke level owing to deposits in the pot.

Where the Conradson carbon figure for a fuel is greater than about 0·5 per cent, considerable difficulties are experienced in operating the pot burner, and fuels where this figure is exceeded cannot be regarded as satisfactory.

An analysis of work carried out on the subject of burner deposits by a large number of workers indicates that there is some relationship between C–H ratio and burner deposits. The higher the ratio, the greater is the deposit. It is, however, not clear what the upper limit of C–H ratio should be, as there is much variation in the figures obtained from different designs of burners.

The pot type vaporizing burner, which is ignited by hand and then controlled thermostatically on the high–low flame principle, appears to give generally the heaviest deposits under reasonable smoke conditions at the low rate of firing. Under good operation and installation conditions the burner will operate for a month or longer before cleaning of the pot is necessary if straight run gas oil is used. The carbon deposited can vary widely and when using gas oil as, for example, that specified in Table V deposits from 20 to 70 p.p.m. on the weight of fuel burnt are obtained.

Various additives have been tried out by workers on the subject, and while it is possible that, in the future, something might be found which will have a beneficial effect, tests under controlled conditions have, up to the present, generally failed to indicate any beneficial results with a large number of proprietary materials.

It is the opinion of the authors that the best trouble free fuel for the pot type vaporizing burner is kerosine. Satisfactory results can be obtained with straight-run gas oils, but cracked oils, blends of these, and blends containing quantities of residue are to be avoided if satisfactory operating results are to be obtained.

As previously mentioned, all these fuels can be burnt satisfactorily on the fully automatic pulverization type of burner.

ACKNOWLEDGMENT

The writers wish to express their thanks to the chairman and directors of The British Petroleum Co. Ltd., for permission to publish this paper.

DISCUSSION

C. W. G. Martin: The authors have attempted to cover a very wide field of energy utilization, and I must confess to a little disappointment that in trying to broaden their field to this extent, they have perhaps restricted it from what I might call the geographical point of view. If I were to use the word "parochial," I think it would be regarded as having a somewhat critical reflection, and I do not mean that at all. But if I may generalize a little, I would say that many papers presented, not only to this Institute, and not only in the U.K., tend to lose a little of their potential value by glossing rather quickly over the points of possible interest outside the country of presentation. This comment, which I hope will not be regarded as anything but constructive criticism, is applicable to one of the early sections of the paper, relating to liquefied petroleum gases. LPG, as sold on the U.K. market, is certainly, as the authors say, the product of refinery operations, and this, in the broad sense, applies to European and foreign markets in general. But, in the U.S.A., which is easily the largest LPG market in the world, it is my understanding that by far the greater part of LPG deliveries into consumption originate from field production. I should be interested to learn if this impression is confirmed by others who may have experience on this particular subject.

Again, in the U.K., distribution of LPG gases is, as the authors quite rightly state, normally in steel cylinders. But in the Americas, large and small bulk distribution to customers (the small ones especially to domestic households) is now also being developed rather rapidly. In Europe and the U.S.A. distribution between the producing point and local bulk stockage points is freely carried out by a variety of methods—pressurized rail tank car, road tank truck, ocean bulk tanker, bulk lighter, and by pipeline—according to circumstances.

It was not my intention to stray outside the precise title of the paper, but I observe that the authors have referred to the use of propane in industry, as opposed to butane for the greater part of the domestic uses. The reference is, again, quite clearly to the U.K., but in the U.S.A. propane is the gas most commonly used in domestic applications. This is an important matter, because the U.S.A., with a household consumption of LPG of approx 5 million tons a year, is by far the largest consumer of liquid gas. Furthermore, Caribbean and South American countries use propane, or at least a propane–butane blend, for household purposes.

As I understand it, the growing trend in Europe, too, is to supply propane—or again a propane–butane blend—for large domestic and commercial consumers, as already, for example, in Denmark.

There was a point which I think escaped Mr Tompkins in his summary, although I am sure he is aware of it. There is a reference in the paper to sales figures for "last year." I think actually they are figures for 1954, not 1955.

One point that I did not see in the paper, and am glad that Mr Tompkins did mention when presenting it, was that LPG gives what we may term "a gas service beyond reach of the mains supply." I would personally have put that ahead of almost all the other advantages claimed for it.

I would like to invite comment from the practical angle on the concluding paragraphs of the liquid gas section of the paper. The authors might perhaps have made the point that, in the case of butane domestic installations with substantial offtake rates, a double installation might be indicated, *i.e.* with the bottles in parallel. In the more extreme cases, a switch to propane might be better. On the industrial side, propane is supplied, for this reason, to all applications requiring the supply to burners with high offtake rates and high injection pressures. For static installations of large consumption, propane or butane can be used, as it is possible to withdraw the butane (or, if necessary, the propane) from the storage tank in liquid phase and employ a vaporizer.

The section on kerosine, as I have said, interested me very much. I was also rather amused by the number of aliases which the authors give to kerosine. It has probably more alternative names than any other petroleum product. One thing which is pertinent, and I was glad Mr Tompkins brought it up, is the fact that many of the names we choose for kerosine, do in fact bear out that paraffin wax was the forerunner of the

petroleum trade proper. If you fancy the Romance languages, you will recognize "paraffine" as a synonym for wax, while the Greek word "keros" means precisely the same thing.

In parenthesis, may I say that I give the authors a good mark, not only for choosing to use the word "kerosine" in the paper, but also for spelling it the way the IP likes to see it spelt!

Reference to the various kerosine space heaters, such as the very effective type shown in Fig 9, tempts me to quote, not for the first time, the figures given by J. A. Oriel, at the inaugural meeting of our London Branch in March 1948.* I am sure you have all read it. These figures were calculated so that they indicated fuel efficiency, in the room, based on the quantity of the original fuel used. This means that the ordinary gas or electric fire, where the heat in the room is derived from the fuel consumed earlier on, to provide the intermediary source of heat, has, so to speak, to suffer two stages of loss of efficiency. The actual figures as they are relevant to this discussion were:

An electric fire produces in the room only 18 per cent efficiency based on the original fuel used; a coal fire produces 20 per cent; a gas fire with town gas, 29 per cent; and a kerosine heater, 93 per cent. Those figures have stuck in my mind ever since I heard them nearly eight years ago, and they are well worth remembering.

The only kerosine appliance on which detailed test results are given in the paper is the smoothing iron. I would very much like to know if the authors have any test data on a similar scale relating to the blue flame heater. I suppose the blue flame heater is, in fact, the most used kerosine appliance today, and it is this which makes me question the authors' comment that the heat output rating of a heater or cooker is largely controlled by the smoke point. Would they say that this comment is still true in the case of a blue flame heater?

The authors have produced some very interesting data in the section on wicks. The Sunbury figures on the drop in flame height with wet wicks are most instructive, and again, I am hoping that there may be comments from other people who may perhaps have done some work on this subject.

I have allotted a great deal of my time to Part I, because I have very little comment to make, in fact, on Part II of the paper. What I have to say could virtually be confined to four of the diagrams—Figs 18, 20, 21, and 22 in the paper. As far as Fig 18 is concerned, the results on a typical pressure jet burner, if one accepts the slight liberty which authors always take, I suppose, in drawing curves, appear to indicate that thermally cracked gas oils are the worst, and marine diesel fuel the best, from the point of view of smoke density. But if one attempts to correlate this with C–H ratio, which, in theory, might have some influence, one finds that the catalytically cracked material, not the thermally cracked, has the highest C–H ratio, and I suppose the straight-run gas oil has the lowest. I wonder if the authors could suggest any other characteristics which might affect the relative position of these curves? They will probably agree, anyway, that if one were to take a better type of burner, as was presumably the case in the tests reported, the apparent differences between fuels can be largely, if not entirely, eliminated.

With regard to the tests made by Standard Oil of Indiana, I have the chemist's usual difficulty of thinking of boiling points in degrees Fahrenheit, and a positive abhorrence of specific gravities going to a fourth place of decimals—but I do not blame the authors for that. I appreciate they have simply taken the results from somebody else's activities. But I would wish to advise caution in the interpretation of the results, shown graphically in Figs 20, 21, and 22. Although side deposits have been correlated with smoke point, and certainly the results appear to show this, they could equally, I suggest, be shown to correlate with other factors, such as, perhaps, C–H ratio, sulphur content, or diesel index.

The comparison is again made between straight-run gas oils and the catalytically cracked fuels, and Mr Murray did say that he was not "getting at" cracked fuels so much as pointing out that this difference shown up on the graph was a question of chemical composition, and that a suitably chosen straight-run material might quite well have given results comparable with some of the cracked fuels. But I think it would be as well to dwell just a moment on this point, because these graphs, after all, if taken out of their context (as they might well be at some later stage) may not be fairly interpreted without Mr Murray at hand to do so. I appreciate the authors' difficulty in that they could not presume to alter someone else's published figures; but in principle, I recommend caution in giving the impression that a fuel of one particular origin or method of manufacture is better or worse than another, without supporting the claim with reliable practical data. For example, here we have five or six fuels. They differ—they are bound to differ—in volatility, in viscosity, probably in sulphur, in half a dozen different characteristics, and I do not think that the slides as we saw them give any clue to these other possible influences.

I was pleased to see that the authors had not overlooked the possibility of additives having some effect on deposits. I have long been interested in the subject of fuel additives, but, once again, I see that these investigations appear to be attended by negative results.

D. G. Tompkins: We have appeared to use the word "domestic" too literally. We have kept the subject, perhaps, too much at home. There are one or two points which rise from Mr Martin's comments. The primary one is that kerosine, as we know it in the U.K., really does not exist in a serious way abroad. I suppose the U.K. is by far the most concentrated kerosine consuming country there is. This, no doubt, is due to the high quality of kerosine in the U.K. The presence of our extremely good, high smoke point, low char value kerosines, encourages us to burn a good deal of it. Therefore, personally, I would say that my experience of kerosine appliances abroad has been somewhat confused by the very high char value which has been found in the fuel that was either used or tested.

Going on to the LPG question, I would support Mr Martin very strongly in this slow but gradual move from butane to, first, butane–propane mixtures, and undoubtedly, finally, to propane in the domestic market. I should imagine that in the U.K. the question of propane content may well depend on the design of the cylinders, of which some million or more must exist. If those cylinders are, in their present design, capable of carrying propane, they may well do so, but they were, in their early stages, designed for butane and will become weaker with increasing age.

Another factor we must remember on the difference which Mr Martin mentioned between the U.S.A. and the U.K., on propane–butane, is the question of climate. In the U.K. we do not have the extremely low temperatures which exist in countries with a Continental climate. Therefore the vaporization of the gas occurs fairly freely with either butane or a low content of propane, whereas in the cold parts of the U.S.A. in winter, one would get no vaporization from butane, which has a boiling point of about 0° C. That is why, as Mr Martin points out, countries like Denmark operate on 50 per cent propane–

* "Petroleum in the Modern World." *Inst. Petrol. Rev.*, 1948, **2** (18), 161–9.

butane in the summer, and may go as high as 70 per cent of propane in the winter.

This mixture of the two gases can lead in extreme cases to an awkward fractionation within the bottle, which can lead to the heavy ends remaining behind, which, towards the end of the bottle's life, gives one the idea that it is empty. That also occurs, as Mr Martin pointed out, in the question of excessive draw-off, for instance. If one does draw too much gas from the bottle, whether it be propane or butane, in the course of vaporization it draws heat from the remaining liquid which rapidly falls in temperature. Eventually, moisture and frost will settle on the bottle, retarding heat flow into the bottle, and the pressure falls away. That, again, is a question of the size of the bottle. As Mr Martin says, the dual bottle system, or a manifold carrying many bottles would reduce the load on an individual container, and enable gas to be drawn at higher take-off rates.

This take-off rate question is a very difficult one indeed, particularly on the distributing side. Manifolding calls for much larger numbers of bottles in order to supply each customer with two or three containers for the same sale of gas which would occur with single bottle installations, if the take-off rate were suitable. It is the introduction of increased domestic loads, such as having a cooker and a water heater, for example, which operate first thing in the morning. Since these appliances call for gas at one and the same time, when the bottle is perhaps relatively cold, pressure drop may occur in the container, leading to failure of the gas supply.

The question of propane on the Continent, and I think Mr Martin will probably support me in this, is a little confused, because much of the propane that is available in countries like Germany is derived from non-petroleum sources, in the sense that it is the product of hydrogenation of a wide range of materials. Whereas in America propane is derived from natural gases, our own propane tends to be from refinery operations, and much on the Continent can be derived from non-petroleum sources, i.e. it may be produced by hydrogenation of heavy crudes, in some cases, or from the treatment of brown coal.

I was very interested in Mr Martin's remarks on the number of names we give to kerosine. I remember that at one time it was known as coal oil, because I believe cannel coal was exported from the U.K. to the eastern part of the U.S.A., the coal being distilled over there to produce what was a kerosine. It seems rather odd to transport material all that way to carbonize it on the spot and produce what must have been very small yields of burning oil. I am also very interested in the remarks on efficiency, but I have not related the figures of efficiency of appliances in quite the same manner as Mr Martin. There is no doubt that electricity and gas, which have to convert fuel to energy in a more transportable form, do yield poor efficiencies. From experiments we have done, and we have not done a great deal on the real efficiencies of appliances, we believe that over 98 per cent of the kerosine is fully burned in blue flame heaters, and therefore it does attain 98 per cent of the net heating value of the fuel. We cannot use the gross value because the water must remain uncondensed in the room in which the kerosine is burned. That is one of the reasons why I stress ventilation so much. It is important to remember that you get roughly a pound and a quarter of water for each pound of kerosine burned. It is difficult to persuade customers that you are not selling water when you stress that. They all say, "I did not know there was so much water in your kerosine."

With regard to the other point on efficiency, I would say that a good blue flame heater should give virtually complete combustion of the fuel, and should therefore release the net calorific value of a fuel.

On the question of wicks, I am very glad that Mr Martin supports this view of the care of them. I consider it a very much abused part of the equipment. People think a cotton wick requires no care taking of it, and in view of the climate (particularly where we have had experience with refrigerator use) in tropical areas, where humidity is very high, the wet wick can prevent the burners from functioning correctly.

G. F. J. Murray: Referring to Fig 18, Mr Martin states that the relative positions of the curves would be altered if they were based on C–H ratios, and were not given the terms "straight-run gas oil," "marine diesel oil," and the like. I think that is probably true, but it really does not alter the picture very much. After all, we know that thermally cracked gas oil has a higher C–H ratio, but it can still mean that the smoke density for a given excess air figure would be higher with that oil than with a straight-run gas oil under similar conditions of operation.

In his next point, dealing with comparisons of results in Fig 18, and I think he was referring to the figures given in Table VIII, they are carried out on the same burner and with the same oil. But I would remind you that these are results obtained in a laboratory. They cannot be directly related to the conditions which apply in service, where thermal efficiencies of the oil are 70 per cent, and would be very much the exception rather than the rule. The general conclusions we draw, however, can be applied to normal service conditions.

Mr Martin also raised the vexed point concerning the various graphs shown in the later figures. Correlation could probably be obtained with sulphur content, C–H ratio, or diesel index. In general, the sulphur content of a cracked oil would naturally be expected to be higher than that of a straight-run oil, and one would also expect the diesel index of a straight-run oil to be higher than that of a cracked oil.

I would like to stress, however, that there is comparatively little information available on this subject of deposits in the pot of the vaporizing burner, and it is important that we carry out more and more tests in the future related to oil characteristics, because this type of burner is becoming very popular, not only in the U.K. but abroad.

I would like to refer back to the rather "parochial" outlook to which Mr Martin referred. That criticism is justifiable up to a point, but properly controlled tests on such burners have not been carried out to anything like the degree required, or if so they have certainly not been published. The results given in the paper should be of universal application and, at least, applicable to the European market.

On the question of the chemical composition of cracked gas oils compared with straight-run oils, Mr Martin's remarks are to the point. If burner performance can be shown to be truly related to the chemical characteristics of the fuel, then it is clear that the names of particular fuels are unimportant. It may even be that a straight-run oil could be found similar in composition to the cracked oils I have given. We have not, however, seen such a material, and if Mr Martin knows of one I am sure members of this Institute would be glad to have details of it. As I have mentioned before, as far as we are concerned an alteration in name will not alter the overall picture, and if we use the common names everyone will at least know what we are talking about.

We briefly mentioned the subject of additives. As probably most of those interested realize, one could present a paper on additives in themselves, and we have, therefore, kept our remarks to a minimum. Proprietary additives claim, as you know, that they can do anything but pay the baker and the butcher, but I must say that the results of tests which have come out so far have failed

to indicate any great advantage, under carefully controlled conditions, being obtained with the various additives which are now on the market.

G. J. Gollin: I would first like to comment on Fig 16. I think there must be something wrong with the figure. If you put some oil in a bucket and make a hole in the bottom, then as the temperature falls you get an increase in viscosity and a decrease in flow through the hole. In contrast, the characteristic feature of the pressure jet atomizer is that the relationship goes the other way, that is, as the viscosity increases the output increases, as shown in Fig 16. However, it does not continue to increase indefinitely. When the atomizer stops atomizing, the curve starts to drop. Perhaps I have confused cause and effect. In any case, the initial part of the curve from the low viscosity end to the point of inflexion represents the zone in which the nozzle is truly atomizing and beyond that atomization is impaired. The quality of a pressure jet nozzle can be judged to a certain extent by the viscosity at which this point of inflexion occurs. The nozzle quoted in the paper has a very remarkable characteristic in that the viscosity of the oil goes up to 250 seconds Redwood I and yet the output has not begun to fall. This is better than the performance of any British-made pressure jet nozzle which I have ever seen. I would like to know whether the draughtsman who made the curve prolonged it indefinitely or whether on test the nozzle really did go on atomizing at 250 seconds Redwood I.

The authors say that, in the case of vaporizing burners, incorrect installation and unsuitable fuels are some of the reasons for poor operating results. I agree with them, but I think there is another very important factor, and that is the difficulty of metering accurately very small rates of fuel flow. The orifice is usually small, and the flow is not only affected in change in viscosity of the fuel, but these tiny orifices, which tend to act as fairly efficient filters, clog gradually and the rate of flow can change. It is very difficult to know at any time the precise rate at which a vaporizing burner is burning the fuel, and I think this is particularly true in those periods when a burner is changing over from its minimum flame (its standby flame) to high flame, or vice versa.

There is a formula for the output of a given pressure jet which contains the factor "C"—nozzle discharge coefficient. Whole volumes have been written on factor "C," and unless one knows what it is, one cannot use the formula for deciding what will be the output from the nozzle. Still, the formula does give you the idea, that the output varies roughly with the square root of the pressure and inversely with the square root of the density of the oil. I think it should be made clear that the formula represents the output in volume, *i.e.* gal/hr, because I think that if the output of a pressure jet nozzle is expressed in weight (lb/hr), then it varies directly as the square root of the gravity.

There is rather a curious paragraph, in which the author suggests that high viscosity and high gravity are themselves the cause of poor operation. The paragraph says, "Therefore oils combining high values of these two properties can give difficulties with some burners, the high throughput usually causing flame instability and poor combustion." I should not have thought that an increase in output from the nozzle of, say, 5 or 10 per cent, could in itself be regarded as a primary cause of bad burner performance. It is true that if the burner had been adjusted to give a good performance on one grade of oil, and then you changed over to a grade of oil that effectively gave 5 per cent more through the nozzle, you would upset its performance. But I should have thought that you could change to another oil which, due to a higher gravity or a higher viscosity, increased the output by 5 or 10 per cent, and then readjust the burner. If the burner was of reasonable quality, it would give equally good results.

With regard to the curve shown in Fig 18 it would be interesting to know what was the atomizing pressure employed. Presumably this fully automatic pressure jet burner was operated at 100 p.s.i. I would like to know whether the engineers who carried out the tests repeated them with other atomizing pressures because it is possible that if the curves were obtained at 100 p.s.i. and further tests were carried out at 150 p.s.i., then the results obtained on the same five oils might not appear in the same order of merit. The atomizing pressure exerts a powerful influence on such excess air–smoke density characteristic curves.

Table VII is very interesting. This is for deposits given on a plate put in a boiler. It is not clear whether the plate was placed in the primary combustion chamber or in the secondary passages, but on looking at the tabulistics of deposits, you see that they weigh about 2¼ lb/cu. ft., and that the thickness of the deposit was something of the order of one thou. I think one can deduce that from these figures. Now, 2¼ lb/cu. ft. is rather light for soot, and so it would be interesting to know whether the people who carried out those tests could provide an analysis of what these deposits were and whether the actual steel plate on which the deposits were collected was at a temperature near to that of the products of combustion passing over it, or near to that of the walls, which were water cooled? This might have quite a strong effect on the rate of deposits on such a surface.

Finally, I agree with the authors that many of these vaporizing burners, both natural draught and fan-assisted, do give better results, and run longer without cleaning, if the fuel selected is kerosine, rather than domestic oil.

G. J. F. Murray: Mr Gollin suggests that the curve on Fig 16 is not indicative of the characteristics of a pressure jet type nozzle on the burner which we were testing. That is quite true. Nevertheless, the curve does show what might be anticipated in the operation of such a nozzle, namely, increasing viscosity of the oil in the burner. The curve falls at the end, as Mr Gollin has said, but we are concerned only with its first part, where atomization is obtained. The curve is not related to any nozzle on the normal fully automatic pressure jet burner, but is given only to illustrate the point above. Normally one would never use a 250 seconds oil on such a burner. You would have to go to some different type of burner, the heavy oil type, and there conditions may be very different. The formula refers to the output of the nozzle in gal/hr, and in this connexion I do want to bring in this question of the unsatisfactory operation we have experienced in certain cases of pressure jet burner, when using oils of high viscosity and high gravity. I am speaking relatively here, in the gas–oil range, where we have experienced flame instability. We have not adjusted the burner in each case, because the consumer does not adjust his burner. The consumer has his burner adjusted to certain given conditions, and then for some reason you get an oil having a higher gravity, and perhaps a higher viscosity. On certain critical types of burner we have experienced this, and the formula and the graph have been given in the paper to indicate that sometimes poor operation of burners is obtained when the oil characteristics vary.

The distillation range of the oil might also have an effect, and there is a great deal more work required on the combustion problem for such burners, related to these particular characteristics and other oil quality factors.

On Fig 18, Mr Gollin mentioned the question that if the pressure was increased to 150 p.s.i you might get a totally different picture. We have worked at higher

pressures, and in general we get the same type of picture. You must realize that in a normal burner, again it is set, and if different oils are delivered to it, then you get a picture like this. Now, those conditions can be improved by altering the air slide, increasing the pressure, and so on. As I have indicated in my paper, provided that the burner is adjusted correctly, all these oils can be burnt very satisfactorily. But that does not alter the relative position of these oils for a given setting on the burner.

On the density of the deposits, Mr Gollin has said that if the plate, which was, by the way, suspended in secondary heating surface passages of the boiler, had been cooled, one might get a different picture. That is possible; one might. But it must be realized how difficult it is to get such practical conditions in a boiler. The difficulty of measuring the quantity of deposit by scraping all the heating surfaces very thoroughly after each run, or after each test, must also be realized. It is, therefore, hoped that by suspending a plate in the gas passages, that it is, if not an absolute indication of what is happening, at least a comparative one. Again, more work should be done on this subject. Of course, it does mean that that plate would be at the approximate temperature of the products of combustion which pass over it.

I agree with Mr Gollin on his remarks concerning the difficulty of metering small rates of flow, particularly with vaporizing burners using gas oil. Wax deposition on the needle of needle valves seems to be the cause of the trouble. This causes wide variations in fuel flow at a given setting and unstable burner operation. More work is required on the design of such valves, but whether a solution of the problem will be obtained is a moot point.

A. B. Pritchard: When dealing with fully-automatic pressure jet burners, Mr Murray makes a statement that boilers of ratings in excess of 250,000 B.t.u/hr can be fired with this type of burner using 200 seconds fuel oil.

I have had a little experience with this type of burner and, by and large, I would hesitate to recommend that they should be used with 200 seconds oil on boilers rated at less than 450,000 B.t.u/hr. It does occur that some installations comprising several large boilers also include a small boiler rated between 200,000 and 350,000 B.t.u/hr. In these cases, the small boiler has to be fired with 200 seconds oil to avoid employing a dual fuel system. In my experience, these small boilers are almost invariably troublesome and inefficient due to the inability of the burner to produce good combustion conditions at the relatively low oil consumption rates involved.

I do suggest that it may result in unnecessary trouble if people get the idea that boilers in the range 250,000 B.t.u/hr to 450,000 B.t.u. should be fired with 200 seconds fuel oil and insist that their single boiler installation should be put on to this grade.

G. F. J. Murray: I think that if one employs 200-second burners, particularly some of those of more modern design, on boilers of the order of 250,000–300,000 B.t.u/hr, satisfactory operation can be obtained providing the burner has not to stand up to an excessively large amount of starting and stopping.

We have had good experience with the modern design of 200 seconds fully automatic burner with ratings as low as that mentioned in the paper. For the conditions which apply in many blocks of flats, offices, and other buildings with low heat capacities, demanding rapid response of heating systems with rapid and severe cycling on the burner I agree with Mr Pritchard that 450,000 B.t.u/hr is the desirable minimum boiler size. A 200-seconds fuel can be a most efficient fuel on such burners if the mechanical devices on the burners work as required by the necessary cycling of the installation. Smoke levels and combustion efficiency figures may in many instances be better than with numerous gas-oil burners of the same type.

L. G. Blyther: I would like to make some remarks relating to Part II of the paper, in particular to equipment used for oil firing, rather than the quality of the oil. When conversion is made from solid fuel firing to oil firing, it is generally found that the oil flame gives less radiation to the hot water jacket, so that it is necessary to transfer more heat by convection if the boiler efficiency is to be maintained. Boiler manufacturers are by now well aware of this and make a practice of modifying existing boilers for oil firing, by using baffles, or, alternatively, re-designing completely to give more convective surface.

What is perhaps less generally realized, in converting or re-designing for oil firing, is that the arrangement of the combustion chamber, in relation to the burner, is important, and should be studied, with a view not only to increasing radiation from the flame to the wall, but also to promoting good combustion. For example, many pressure jet burners, of about a gallon per hour fuel rate, cannot be operated at more than about 90 per cent CO_2, that is with 70 per cent excess air, without making visible smoke. This is bad both in affecting boiler performance adversely, and also in increasing the possibility of sooting of the gas ways of the boiler. Now, it seems to me that it is just as important to shape the combustion chamber to suit the flame configuration as it is to promote good oil–air mixing, by means of a combustion head. I feel that attention to the design of the combustion chamber is a safeguard, not only against loss of boiler efficiency due to operation at low CO_2, but also against harmful production of soot in the gas ways of the boiler. I think that is a point which is important and to which attention should be given.

G. F. J. Murray: I could not agree more with the last speaker. The design of the combustion chamber inside the boiler is of vital importance. I am not quite in agreement with him on the question of radiation in the solid fuel type of boiler. I think conduction plays a very great part, particularly when you have a deep fuel head, and of course, in that connexion, with boilers in the U.K., as has been pointed out by Mr Gollin, the secondary heating surfaces are not really sufficient to get the maximum efficiency and to get high thermal efficiencies and low exit gas temperatures. With these conditions, the consideration of the use of economizers or extended secondary heating surface is very necessary, with, of course, the minimum of sooting-up of gas passages. That sooting-up can occur if you have bad combustion, and a bad combustion chamber.

I would like, however, to add to what the last speaker has said, in the type of refractories which are employed in the combustion chamber, I think that the use of hot face insulation should be more general than it is at present. Hot face insulating refractory bricks cost little more than the normal alumina type; nevertheless the rate of heating up of the former is very much more rapid and the smoke production, which is at the maximum when a burner starts up and the combustion chamber is cold, is reduced, because the speed at which the refractory heats up is very much greater. I think that designers in the U.K, should consider the use of hot face insulation more than they have done in the past. The question is well appreciated in the U.S.A. by burner and boiler manufacturers.

G. L. Kennaby: There are two questions I would like to ask the authors. One is in connexion with the catalytic burner. Have they any knowledge as to what percentage of sulphur there is in the narrow cut range of gasoline that is used, and whether it is found that the

sulphur has any effect, or is known to have any poisoning effect on the platinum catalyst used?

The second one is, have they any information on the use of other material apart from cotton, for the manufacture of wicks, such as glass wool, asbestos, or synthetic fibres?

D. G. Tompkins: On the question of the sulphur content of the fuel for the catalytic stove, I have the impression from figures I have seen that it would be about 0·04 per cent. Again, so far as I know, the loss of efficiency of the catalyst bed is due to the presence of high-boiling fractions which the catalyst cannot handle rather than from poisoning by sulphur. I understand that the choice of the 70°–100° C cut for this job is that in France a material with more than 5 per cent distillable at 70° C becomes taxable as motor spirit, and this sets the lower end of the distillation range. Anything which boils over 100° C cannot be coped with by the catalyst, and therefore we are set between those two points. So far as I can understand from contact with firms making stoves of this kind, it is mainly loss of efficiency from the accumulation of fractions in the catalyst bed which cannot be catalysed rather than the influence of sulphur.

Dealing with the question of wicks, a great deal of work has been done on alternatives to cotton wicks, but so far as I can find out from discussing it with a wide range of people, the only things one can use are glass fibre and asbestos. Glass is very friable indeed, and like asbestos has apparently poor capillary properties. These fibres have poor wetting properties with oil, and do not carry very much kerosine. Obviously one cannot use any of the new synthetic fibres because they will melt at flame temperatures. Things which are thermoplastic by nature of the way in which the fibre is formed, such as the acetate silks, Terylene and nylon, would melt and sinter the surface of the wick and render it impervious to oil. So far as I know, glass and asbestos have not succeeded in ousting cotton. It is not solely economic reasons—I think the poor oil-carrying property of asbestos is one of its drawbacks. In the case of glass fibre wicks which have to be positioned about by any kind of sprocket I think there would be a great deal of crushing or tearing.

N. M. Lawrance: With reference to Fig 16, Mr Gollin has already pointed out that if the output of a simple pressure jet atomizer is plotted against fuel viscosity for a given pressure a curve which has a peak in it will be obtained. At viscosities higher than that at which the peak occurs atomization is unsatisfactory or does not take place, whilst at viscosities lower than that at which the peak occurs proper atomization will be obtained. I should like to go on to point out that as the size of the atomizer decreases so the maximum viscosity at which satisfactory atomization will be obtained decreases. A lower limit on size is therefore reached which prevents pressure jet atomizers smaller than a certain size for any given fuel being a practical proposition. For example, at 100 p.s.i. a nozzle having an output of about ¾ I.G/hr is unlikely to atomize properly at a viscosity above about 50 seconds Redwood I.

For this reason other types of burners should be employed for installations of, say, 75,000 B.t.u/hr output and less.

In Fig 15 the viscosity limits for good atomization are given as from 70–100 seconds Redwood I. Although this figure relates to fairly large size nozzles using heated heavy fuel, and may represent normal practice, I feel that a lower range, say from 60–80 seconds Redwood I, would be more representative of good practice.

With regard to the smaller domestic boilers, forced draught vaporizing burners can be used in the range 75,000–25,000 B.t.u/hr with good combustion efficiency, but as stated in the paper, they tend to be sensitive to fuel quality. Medium pressure air atomizing burners will also cover this range, and they have the advantage that they are fully automatic and not sensitive to fuel quality. The emulsion type of atomizer is one variety of this type. Combustion efficiency with all three types of burner depends on a sufficient pressure drop across the air director coupled, of course, with good air director design. As stated in the paper, really good combustion efficiency, *i.e.* 12–14 per cent CO_2 without visible smoke, can only be achieved if the air director is designed for a pressure drop of not less than about 0·5 inches water gauge across it. Many pressure jet and other types of burner, however, employ a pressure drop of only about half that amount, and with these it is usual to find that the visible smoke belt is entered by the time the excess air has been reduced to about 70 per cent corresponding with 9 per cent CO_2. For this reason good forced draught air directors should always be fitted to all types of burners including those employing air atomization.

Incidentally, the pressure drop across the air director of forced draught vaporizing burners in my experience is usually sufficient to give good combustion efficiency at the maximum firing rate and is appreciably higher than the figures given, which would be applicable to a natural draught burner.

In Fig 18 all readings are taken at excess air quantities of 80 per cent and above. These excess air quantities seem to be rather above normal practice and are certainly above good practice. It would be interesting to know why these tests are done under these conditions.

Fig 23 shows an interesting relationship between the Conradson value of the fuel and the deposits formed in a pot type vaporizing burner. Unfortunately, the deposits in vaporizing or partially vaporizing types of burners do not always seem to be related to the Conradson value of the fuel.

This paper is on the quality of fuels. So far as gas oil and heavy oil burners are concerned I would like to say that, generally speaking, the excellence of the equipment and of the performance it will give is of far greater importance for good results than the quality of the fuel, except in the case of vaporizing burners. Good burners are not affected by small changes in the fuel because they can be set to give satisfactory results well within their capabilities, whereas bad burners are easily upset by small changes in the fuel because they must be set to the limit of their capabilities in order to give an overall efficiency from the plant which is not unacceptable.

G. F. J. Murray: First of all, I think the figure starts at about 60 per cent, or just over. The point is, why did we choose a figure of about 80 per cent excess air, corresponding to 0·6 milligrams of soot/cu. ft?

Undoubtedly, in a laboratory, you can get much lower excess air figures. That is quite true; but from the large number of burners which I have seen in the field, 80 per cent is round about the figure which is generally obtained. It must be remembered that we are supplying the fuel to a large number of oil burners, and we cannot go round and adjust each one so that it is exactly correct. If something goes wrong, the blame is put on the fuel, and we certainly cannot go round and put everyone's house in order. So that the figure of 80 per cent really was chosen as being a usual everyday figure which is obtainable on a large number of oil installations receiving no attention from the householder, burner maker, or oil supplier.

Regarding Fig 23, you mention the difference in correlation. I did point out that this correlation is related to the use of gas oils mixed with residues as blends, and it may well be that the lower ends will give different results.

Further, of course, and it is a very important point,

with certain types of burners, those figures do not relate exactly. It is always a difficulty to know how one should work out this deposit question related to the characteristics of the fuel. That is the reason why the standard pot burner has been mentioned in the paper, and it is quite likely that on other burners the deposits will be much less, or even might not follow the same curves. Then what is one to do? Test every burner, which is a very large job, or use some sort of standard? We feel that a standard something like this will give us the worst picture, and therefore if we meet that standard, our oils should also meet the requirements of the market.

On the question of gas oil burners and the quality of equipment, I agree wholeheartedly. If one has a first-class burner, well designed, and properly installed, particularly the electrical equipment, one can get a much better result, with a wider variety of fuels, than with a poorly designed burner. But as fuel suppliers, the oil industry has to meet all cases, and therefore that is the reason why we have chosen a typical burner, one which is not too bad, but not too good. If we choose the best one, we get a wrong picture; if we choose the worst one, we also get a wrong picture, so we have tried to steer a middle path, and that, as far as we can see, is the only way in which we can deal with this question of fuel quality for such applications.

D. A. Hough: I have recently seen two ordinary solid fuel boilers which had been converted to oil by the nozzle and pump method. They produce a large flame which makes a tremendous noise, and give the impression that a very considerable amount of heat was going into the boiler. Is such heat detrimental to a boiler designed for solid fuel, and also is it going to be detrimental to the chimney?

G. F. J. Murray: First of all, there should not be the high temperatures that have been indicated in the chimney. If the burner has been installed correctly, one should get a reasonable exit gas temperature, which should not be higher than 400°–500° F, and perhaps lower.

With regard to the flame, if an oil burner is put into a boiler, no flame should come from the front door, and if the refractory combustion chamber is designed correctly there should be no deleterious effect on that boiler, providing that there is no flame impingement on the metal surfaces. I feel that perhaps in this case there is a rather large burner, fitted to a small boiler, operating probably at a high excess air figure, giving a nice bright flame, which everybody thinks is excellent, but which, in fact, from a heat economy point of view, is just what is not required.

Lt-Col. S. J. M. Auld: I would like to have heard a little more about the particulation of smoke and soot deposits, or, really, their negative agglomeration. Perhaps you could tell us whether there is anything relating, for example, sulphur content of fuels to the nature of deposit that accumulates, rather than its quantity.

G. F. J. Murray: Respecting the question of the sulphur content, you are not speaking, of course, of the deposits inside the boiler, but what happens once they get away from it. I think we are just on the threshold of knowledge on this question. There has not been sufficient attention paid to this, and we must do more. The work to be carried out must be related to: (*a*) The particulate matter, soot, etc., and (*b*) The gaseous compounds present, particularly SO_2 and SO_3.

A study must be made of the size of the particles, their composition, and the amount of adsorbed material on them. It is only recently that interest has been expressed in this question, following the report of the Beaver Committee.

There are also indications from the latest work of the Fuel Research Station and others that SO_3 may well be more important than has been thought in the past. SO_2 has always been considered the important contaminant, but the minute quantities of SO_3 in the atmosphere possibly cause far more trouble in respect of the "smog" problem.

It may well be that the smoke produced many years ago reduced the effect of SO_3, and this is perhaps an explanation of the difference between the present day "smog" and the old fashioned "pea souper." However, there is now a larger amount of high sulphur fuels being burnt over a wider geographical area. This may also be an explanation. A great deal more active research work is required on the question of "smog," and the oil industry is working very hard on the problem.

A vote of thanks was accorded with acclamation.

EFFICIENCY OF PACKED COLUMNS FOR EXTRACTIVE DISTILLATION *

By F. H. GARNER,† O.B.E. (Past-President), S. R. M. ELLIS,† and W. H. GRANVILLE †

SUMMARY

In packed columns with the systems methyl*cyclo*hexane–toluene and methyl*cyclo*hexane–toluene in the presence of furfural, it is found that there is a maximum efficiency or minimum ($HETP/Ma$)(Gm/Lm) value at an optimum velocity which closely approaches the loading velocity. In the latter system if the packed column is operating below the loading velocity, increasing the solvent concentration does not affect the ($HETP/Ma$)(Gm/Lm) value. On the other hand, at higher velocities above the loading velocity, increasing the solvent concentration increases the ($HETP/Ma$)(Gm/Lm) value.

NOMENCLATURE

Dp	Packing diameter (inches)
G	Vapour rate (lb/hr/ft²)
Gm	Vapour rate of key components (16 mol/hr/ft²)
$HETP$	Height equivalent to a theoretical plate
HTU_G	Gas film HTU (height of a transfer unit)
HTU_L	Liquid film HTU
HTU_{OG}	Overall gas film HTU
L	Liquid rate (lb/hr/ft²)
Lm	Liquid rate of key components (lb mol/hr/ft²)
n	Number of plates of slope M
M	Slope of equilibrium curve
Ma	$\Sigma nM/\Sigma n$
Ug	Vapour rate (ft/sec)
Ug_L	Vapour rate at loading point (ft/sec)

INTRODUCTION

A KNOWLEDGE of efficiency, as expressed by $HETP$ or HTU, is needed for the accurate design of packed distillation columns. The efficiencies of packed columns for binary distillation systems operating under total reflux or batch conditions have been extensively studied, but little information is available on continuous and extractive distillation systems.

Under total reflux conditions, Kirschbaum,[12] Murch,[13] and Fisher and Bowen [7] have shown that the $HETP$ is a complex function of the boil-up rate giving maximum and minimum values of $HETP$. However, the correlations of experimental results proposed by Furnas and Taylor,[8] Deed, Schutz, and Drew,[3] Duncan, Koffolt, and Withrow,[5] and Robinson and Gilliland,[15] have either neglected the effect of the boil-up rate, or have included it in a very simple form.

Carswell,[1] Peters and Baker,[14] Kirschbaum,[12] and Murch [13] have indicated that the $HETP$ of a packing increases with the packing diameter, which is contrary to the results of Furnas and Taylor,[8] who concluded that the HTU_{OG} was independent of the packing diameter. Fenske, Tongberg, and Quiggle [6] showed that the $HETP$ increased with packed height, and this is supported by Murch,[13] who found that the $HETP$ was proportional to the packed height raised to the power 0·33.

Finally, the work of Furnas and Taylor,[8] Deed, Schutz, and Drew,[3] and Duncan, Koffolt, and Withrow [5] has shown that the HTU_{OG} increases with the relative slopes of the equilibrium curve and operating lines.

Experimental work on extractive distillation has been very limited, particularly for packed columns. Dicks and Carlson [4] have suggested that the $HETP$ would be increased in extractive distillation due to dilution and viscosity effects.

The purpose of this paper is to investigate those factors which influence the $HETP$ of packings in the binary system methyl*cyclo*hexane–toluene and the extractive distillation system methyl*cyclo*hexane–toluene–furfural.

EXTRACTIVE DISTILLATION PILOT PLANT

The experimental results presented in this paper were obtained on an extractive distillation pilot plant which was designed and constructed by Hall.[10] It consisted essentially of a main extractive column and the stripper column. A simplified flow diagram of the plant as used in most of the extractive distillation experiments is shown in Fig 1, but the plant was designed so that it was relatively easy to adapt the apparatus for total reflux and continuous runs on binary mixtures in the extractive column. The extractive distillation column A was 22 ft high and fabricated from 2-inch standard iron pipe. It was packed in eight sections with $\frac{1}{4} \times \frac{1}{4}$-inch unglazed Raschig rings, each section containing about 21 inches of packing. These packed sections were separated by a distributor-sampling device based on a design due to Professor M. R. Fenske. The stripper column B was also fabricated from 2-inch standard iron pipe and packed to a depth of 10 ft with $\frac{3}{16}$-inch Fenske "Nirosta" helices, which were kindly supplied by Professor M. R. Fenske. Both columns were operated under adiabatic conditions by means of jacket heaters and thermocouples placed in the columns, on the column walls, and in the jackets. All the heat inputs were measured on the necessary instruments located on a main control panel. Where possible, gravity feeds were used but pumps C, D, and E

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were necessary to recycle the solvent to the solvent storage tank F to pump the solvent to the extractive column, and to pump the extract to the stripper column. Flow rates were measured with rotameters, and the flowing liquid was pre-heated to the required temperatures before entering the columns. Nitrogen was used as a pressure transmitting medium for measuring the pressure drop through each column and also the reboiler liquid levels.

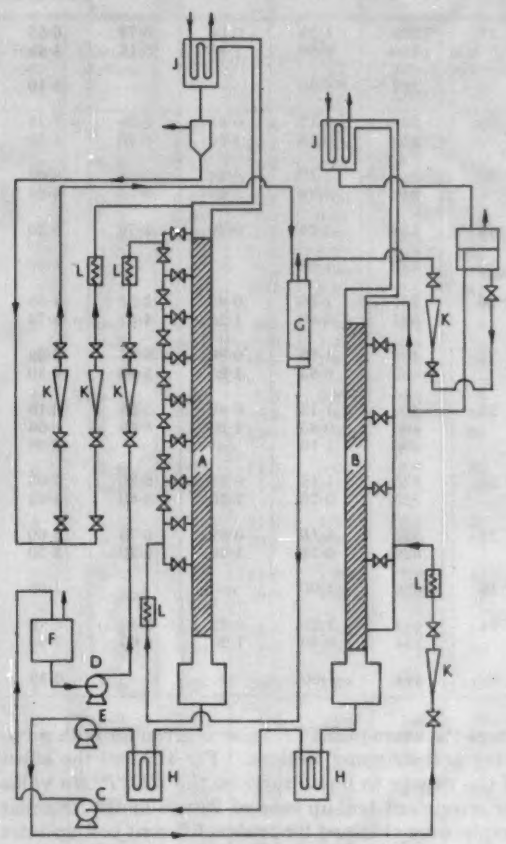

FIG 1

SIMPLIFIED FLOW DIAGRAM OF EXTRACTIVE DISTILLATION PILOT PLANT

A—extractive distillation column; B—stripper column; C—solvent storage pump; D—solvent feed pump; E—extract pump; F—solvent storage tank; G—hydrocarbon feed tank; H—liquid coolers; J—condensers; K—rotameters; L—preheaters.

EXPERIMENTAL METHODS AND RESULTS

(1) HETP *Results for Methylcyclohexane–Toluene Mixtures*

The extractive column was first calibrated under total reflux conditions using a binary mixture of methyl*cyclo*hexane and toluene to determine the effects of boil-up rate and the slope of the equilibrium curve on the *HETP* of the packing. Before each run the column was pre-flooded to give a pressure drop equal to 60 inches of water, and then allowed to settle down to equilibrium at a particular boil-up rate. Samples from various points were used to determine the *HETP* for each section of the column. The vapour–liquid equilibrium data of Hall [10] were used.

A summary of the *HETP* data obtained under total reflux conditions is presented in Table I. It can be seen that the *HETP* varies with the average slope of the equilibrium curve, *Ma*. Fig 2 shows that *HETP*/*Ma* ratio varies with the boil-up rate. A minimum value of *HETP*/*Ma* is obtained at a boil-up rate of 360 lb/hr/ft^2, which corresponds to the loading velocity under total reflux conditions, as determined from pressure drop measurements.

TABLE I

Effect of Ma *on* HETP *for Binary System at Total Reflux Conditions*

Run	Vapour rate (lb/hr/ft^2)	*HETP* (inches)	*Ma*
1	628	7·0	0·93
2	494	6·55	1·1
	494	5·2	0·83
	494	6·0	0·9
	494	5·35	0·88
4	327	5·1	1·0
5	269	5·8	0·98
6	210	4·3	0·84
	210	5·9	1·15
7	403	5·2	0·9
	403	8·2	1·4
8	360	4·42	0·99
	360	5·52	1·33
3	436	5·7	0·86
	436	7·5	1·16
9	424	5·9	0·90
	424	5·5	0·86

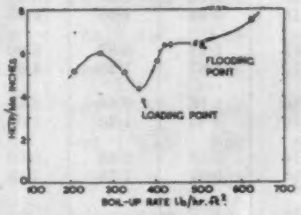

FIG 2

EFFECT OF BOIL-UP RATE ON *HETP*/*Ma* UNDER TOTAL REFLUX CONDITIONS

The column was then operated continuously in order to determine the effect of the liquid to vapour ratio. For these runs the apparatus was arranged as shown in Fig 3 and the results are given in Table II.

TABLE II

Correlation of Continuous Binary Data

Run no.	G (lb/hr/ft²)	$\frac{Gm}{Lm}$	Ma	*HETP* (inches)	$\frac{HETP}{Ma}$ (inches)
18	280	1·25	0·87	6·45	7·40
	280	0·75	1·15	4·67	4·05
19	280	1·25	0·85	5·85	6·90
	280	0·75	1·15	5·25	4·55
20	277	1·25	0·87	5·84	6·70
	277	0·72	1·15	3·96	3·45
21	281	1·33	0·83	5·52	6·65
	281	0·75	1·15	4·46	3·88
35	275	1·18	1·00	7·00	7·00
	275	0·84	1·35	5·25	3·90
39	275	1·78	0·80	7·50	9·40
36	275	1·18	1·00	5·84	5·84
	275	0·91	1·38	5·54	4·00
40	280	1·00	—	—	5·90
37	194	1·20	1·00	5·80	5·80
	194	0·79	1·45	5·54	3·82
38	212	1·25	0·88	5·53	6·26
	212	0·85	1·46	5·84	4·00
41	210	1·00	—	—	5·14
10	394	1·11	1·90	5·25	5·33
	394	0·94	0·90	4·56	5·07
12	388	1·25	0·88	5·54	6·28
	388	0·83	1·10	5·25	4·76
13	388	1·25	0·88	5·85	6·53
	388	0·83	1·10	5·00	4·54
43	390	1·67	0·84	6·00	7·14
	390	1·25	0·80	3·80	4·75
26	397	1·18	0·85	3·86	4·55
	397	0·80	1·25	4·67	3·74
29	369	1·18	0·88	4·56	4·18
	369	0·77	1·25	5·05	4·03
30	369	1·18	0·88	5·62	6·40
	369	0·83	1·20	5·82	4·85
11	410	1·11	0·86	5·50	6·40
	410	0·94	1·00	6·45	6·45
25	413	1·17	0·87	5·00	5·75
	413	0·87	1·25	4·50	3·64
33	310	1·16	0·88	5·40	6·15
	310	0·83	1·30	5·90	4·54
34	310	1·16	0·88	5·60	6·35
	310	0·91	1·38	7·40	5·35
43	310	1·00	—	—	5·10
14	327	1·28	0·84	6·18	7·35
	327	0·81	1·10	4·76	4·34
15	327	1·31	0·88	6·00	6·82
	327	0·80	1·10	5·25	4·77
16	324	1·25	0·87	5·60	6·45
	324	0·69	1·10	4·77	4·33
17	320	1·25	0·86	5·73	6·65
	320	0·66	1·15	5·12	4·45
4	327	1·00	—	—	5·10
31	340	1·17	0·88	6·36	7·25
	340	0·78	1·20	5·40	4·50
32	340	1·17	0·86	5·16	6·00
	340	0·78	1·25	5·75	4·60
44	338	1·25	0·70	3·70	5·30
45	330	1·00	—	—	5·20
26	397	1·18	0·85	3·36	4·55
	397	0·80	1·25	4·67	3·74
27	400	1·13	0·88	5·84	6·63
	400	0·83	1·25	5·40	4·30
28	400	1·13	0·88	5·38	6·10
	400	0·83	1·20	5·60	4·66
	400	1·10	—	—	5·60
22	525	1·18	0·88	6·20	7·05
	525	0·78	1·20	5·60	4·65
23	520	1·15	0·87	5·75	6·60
	520	0·71	1·20	4·20	3·50
46	520	1·00	—	—	6·50
24	444	1·25	0·83	5·56	6·70
	444	0·80	1·20	4·66	3·90
47	444	1·00	—	—	6·30

where the average *HETP* value is given for both rectifying and stripping sections. Fig 4 shows the effect of the vapour to liquid ratio on the $HETP/Ma$ value for a constant boil-up rate of 280 lb/hr/ft². Similar graphs were obtained for twelve different boil-up rates varying from 210 to 628 lb/hr/ft². The effect of the boil-up rate is shown in Fig 5 by plotting the values of the slopes of the lines $(HETP/Ma)(Gm/Lm)$, against the corresponding boil-up rate. There is a minimum value of $(HETP/Ma)(Gm/Lm)$, at the loading velocity.

(2) HETP *Results for the System Methyl*cyclohexane–*Toluene–Furfural*

Having correlated the binary data in a reasonably satisfactory manner, it was now possible to attempt the more difficult correlation of extractive distillation *HETP* data, using the ternary system methyl*cyclo*hexane–toluene–furfural and the vapour–liquid equilibrium data of Hall.[10] The apparatus was arranged as shown in Fig 1. The two reboilers were charged with mixtures of approximately the compositions which would be attained at equilibrium. The plant was then run until equilibrium was obtained as determined by a steady temperature distribution throughout the column and by constant compositions of the vapour and liquid samples. It will be seen from Fig 1

TABLE III

Extractive Column

Correlation of Extractive Distillation

HETP Data

Run no.	Column section	$\frac{Ug}{Ug_L}$	*HETP*	$Ma \times \left(\frac{Gm}{Lm}\right)$	$HETP \times Ma \times \left(\frac{Gm}{Lm}\right)$	Mol % solvent
1	Top–2	0·91	4·8	0·87	5·5	70
	2–5	1·07	13·1	1·68	7·8	50
	6–8	1·20	18·2	1·82	9·7	40
2	Top–1	0·91	5·4	1·00	5·4	3
	1–2	0·91	5·1	0·91	5·6	9
	2–3	1·07	6·3	1·03	6·1	50
	3–5	1·07	21·0	1·77	11·8	50
	6–7	1·20	17·5	1·90	9·2	40
	7–8	1·20	19·1	2·01	9·5	44
3	Top–2	0·70	5·7	0·92	6·2	8
	2–3	0·91	7·0	1·59	4·4	70
	6–7	1·13	10·5	1·91	5·5	50
4	Top–2	0·70	5·5	0·87	6·3	6
	2–4	0·88	8·9	1·82	4·9	69
	6–7	1·09	13·1	2·09	6·3	60
5	5–6	1·28	11·0	0·66	16·6	61
	6–8	1·37	7·9	0·95	8·3	50
6	5–6	1·20	21·0	1·55	13·5	62
	6–7	1·29	10·5	0·94	11·2	54
7	7–8	1·25	11·0	1·90	5·8	40
	2–Top	1·07	6·0	1·39	4·3	2
8	3–4	0·83	6·0	1·46	4·1	56
	7–8	0·94	8·7	1·55	5·6	40
9	8–6	1·36	10·5	1·63	7·1	39
10	Top–1	1·13	6·0	1·09	5·5	3
	6–8	1·29	14·5	1·59	9·1	41
11	Top–2	0·92	4·7	1·00	4·7	3
	2–5	0·99	4·5	1·12	4·0	20
	6–8	1·06	10·0	1·85	5·4	38
12	Top–2	1·08	4·4	1·13	3·9	0
	2–4	1·14	4·5	1·00	4·5	2
	6–7	1·22	14·0	1·73	8·1	30
	7–8	1·22	16·1	1·89	8·5	35
13	Top–2	1·07	5·5	1·00	5·5	0
	6–8	1·22	12·0	1·56	7·7	33
14	Top–2	1·18	4·8	1·00	4·8	0
	6–8	1·32	21·0	1·91	11·0	35
15	Top–2	0·72	6·0	1·00	6·0	5
	2–3	0·94	6·6	2·00	3·3	80
	6–7	1·13	11·0	1·49	7·4	40
	7–8	1·13	21·0	2·14	9·8	50
16	2–4	0·88	7·0	1·25	5·6	60
	6–7	1·08	17·5	2·22	7·9	42
	7–8	1·08	21·0	2·16	9·7	50
17	3–5	1·17	16·2	0·74	24·6	70
18	7–8	1·10	7·0	1·95	3·6	63
19	7–8	1·05	7·0	1·17	6·0	70
20	2–5	1·47	—	—	—	70
	6–7	1·55	21·0	1·47	14·3	52
	7–8	1·55	52·5	2·20	23·8	63

TABLE III—*continued*

Run no.	Column section	$\frac{Ug}{Ug_L}$	*HETP*	$Ma \times \left(\frac{Gm}{Lm}\right)$	$HETP \times Ma \times \left(\frac{Gm}{Lm}\right)$	Mol % solvent
21	2–5	1·40	—	—	—	70
	6–7	1·49	21·0	1·60	13·1	52
	7–8	1·49	52·5	2·20	23·8	63
22	2–5	1·42	—	—	—	65
	6–7	1·50	16·2	1·30	12·5	48
23	Top–1	1·20	6·0	1·11	5·4	4
	2–5	1·51	—	—	—	60
	6–7	1·58	21·0	1·84	11·4	49
	7–8	1·58	—	—	—	60
24	Top–1	1·43	7·7	1·00	7·7	7
	2–5	1·70	—	—	—	50
25	6–7	1·65	24·7	1·76	14·0	37
	7–8	1·65	42·0	2·20	19·1	48
26	Top–1	1·38	6·35	1·10	5·7	3
	2–3	1·60	21·0	2·56	8·2	42
	6–8	1·65	17·5	1·48	11·8	40
27	6–8	0·59	7·5	1·25	6·0	50
28	6–8	0·55	6·7	1·39	4·8	50
29	6–8	0·60	6·8	1·42	4·8	50
30	6–8	0·66	6·0	1·16	5·2	55
31	6–8	0·58	6·0	1·28	4·7	50
32	6–8	0·55	8·4	1·82	4·6	50
33	6–8	0·60	8·4	1·70	4·9	50
34	7–8	0·68	4·4	0·89	4·9	46
35	7–8	0·63	3·2	0·72	4·5	49
36	7–8	0·65	4·9	1·10	4·5	50
37	7–8	0·66	4·7	1·15	4·1	49
38	6–8	0·50	5·7	1·33	4·3	52
39	6–8	0·60	6·0	1·55	3·9	48
40	6–8	0·62	6·4	1·36	4·7	53
41	6–8	0·60	5·8	1·21	4·5	54
42	6–8	0·62	12·0	1·95	6·2	60
43	6–8	0·64	11·0	1·65	6·7	54
44	6–8	0·68	9·5	1·65	5·8	63
45	6–8	0·67	9·8	2·00	4·9	63
46	6–8	0·85	15·5	2·30	6·8	61
47	6–8	0·73	9·4	2·04	4·6	65
48	6–8	0·74	10·0	1·91	5·2	60
49	6–7	0·77	7·5	1·70	4·4	60
50	6–8	0·68	6·5	1·38	4·7	63
51	6–8	0·80	9·4	1·77	5·3	63

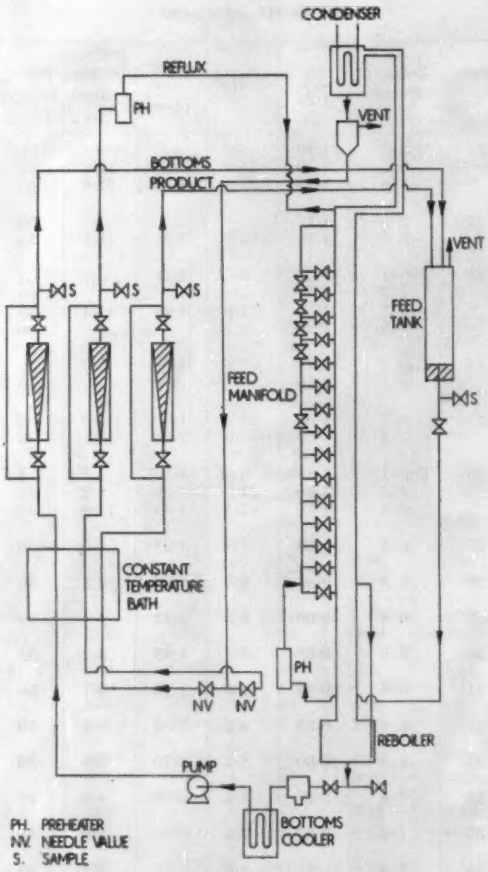

FIG 3

FLOW DIAGRAM OF CONTINUOUS BINARY RUNS

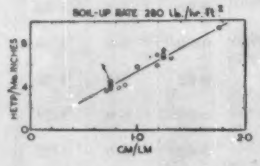

FIG 4

EFFECT OF Gm/Lm ON $HETP/Ma$

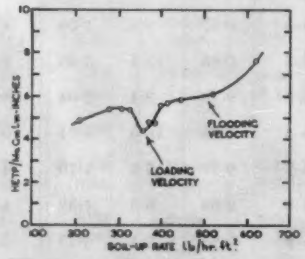

FIG 5

$HETP/Ma$ Gm/Lm V. BOIL-UP RATE

that the composition of the hydrocarbon feed to the extractive column was the same as the sum of the hydrocarbon products leaving the two columns. Further, *HETP* results were also obtained using the extractive column operated as shown in Fig 3. In this arrangement, the column operated as an extractive distillation unit below the feed point by adding solvent to the reboiler. This method gave a good operating line for the stripping section and also avoided a two-phase region in the upper part of the column. The results were evaluated on a McCabe–Thiele diagram using the vapour–liquid equilibrium curve corresponding to the solvent concentration at any point in the column. These *HETP* data are given in Table III, and the results are plotted in Fig 6, where Ug/Ug_L is the ratio of the actual vapour velocity in the column to the corresponding loading velocity. Experimental points were also obtained for 70·0 mol per cent of solvent, but the $(HETP/Ma)$ (Gm/Lm) values were too high to be plotted in Fig 6.

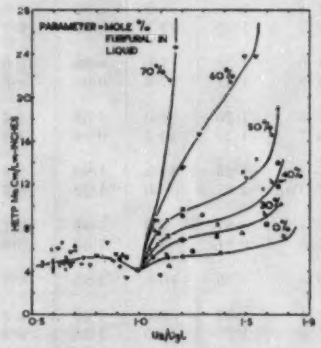

FIG 6

EXTRACTIVE COLUMN: OVER-ALL CORRELATION OF *HETP* DATA FOR BINARY AND EXTRACTIVE DISTILLATION

DISCUSSION OF EXPERIMENTAL RESULTS

(1) *The Correlation of* HETP *Results*

The relationship between overall and individual film resistances is as follows:

$$HTU_{OG} = HTU_G + HTU_L \,.\, M \,.\, (Gm/Lm) \quad . \quad (1)$$

where $M(Gm/Lm)$ is the ratio of the slopes of the equilibrium curve and operating line at that point.

Assuming the gas film resistance is small, equation (1) then reduces to

$$HTU_{OG} = HTU_L \,.\, M \,.\, (Gm/Lm) \quad . \quad (2)$$

For methyl*cyclo*hexane and toluene it is assumed that HTU_L is relatively constant for a given boil-up rate and does not vary with composition since the two hydrocarbons are very similar. Equation (2) becomes

$$HTU_{OG} = \text{const}\ M \,.\, (Gm/Lm) \quad . \quad (3)$$

It may be shown that the *HETP* is equal to the HTU_{OG} when $M(Gm/Lm)$ is unity, and since in these

experiments the values of $M(Gm/Lm)$ did not vary greatly from unity equation (3) was rewritten as follows :

$$HETP = \text{const } M \,.\, (Gm/Lm) \quad . \quad (4)$$

Now Gm/Lm is the reciprocal of the slope of the operating line, and the experimental results have shown that this is constant over any section of the column. This fact was established by plotting the operating lines on a McCabe–Thiele diagram from liquid and vapour sample compositions taken at various points in the column. The slope of the equilibrium curve M varies with composition, and is therefore replaced by

$$Ma = \Sigma nM/\Sigma n \quad . \quad . \quad . \quad . \quad (5)$$

where n is the number or fraction of plates of slope M.

The general equation thus becomes

$$HETP = \text{const } Ma \,.\, (Gm/Lm) \quad . \quad (6)$$

From Fig 2 for total reflux and from Fig 5 for varying reflux it can be seen that the constant varies with

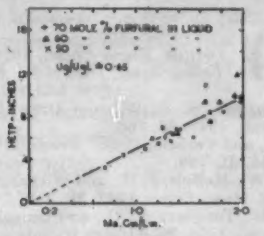

FIG 7

EXTRACTIVE COLUMN : EFFECT OF $Ma.\ (Gm/Lm)$ ON $HETP$ AT $Ug/Ug_L \simeq 0{\cdot}65$ IN EXTRACTIVE DISTILLATION

the boil-up and has a minimum near the loading velocity. At this optimum velocity the $HETP$ is given by

$$HETP = 4{\cdot}3\ Ma \,.\, (Gm/Lm) \quad . \quad . \quad (7)$$

Equation (7) is limited to total reflux and continuous distillations for the system methyl*cyclo*hexane–toluene with ¼-inch Raschig rings in packed sections 21 inches high in a 2-inch column.

In the application of equation (6) to the extractive distillation results, the ratio of liquid to vapour rates varied considerably and different loading velocities were obtained for each experiment and also above and below the point of entry of solvent and feed in each experiment. This difficulty was overcome by expressing the vapour rate Ug as a fraction of the corresponding loading velocity Ug_L. The value of Ug_L was calculated using the experimental loading velocity for methyl*cyclo*hexane and toluene mixtures for L/G ratios equal to unity, and then assuming that the effect of the higher L/G ratios due to the solvent would be similar to the effect of the L/G ratio for air–water.[9]

Fig 6, for the system methyl*cyclo*hexane–toluene–furfural, is thus obtained by plotting $(HETP/Ma)(Gm/Lm)$ against Ug/Ug_L to show that below an optimum velocity which is approximately equivalent to the loading velocity the solvent concentration does not greatly influence the $(HETP/Ma)(Gm/Lm)$ value. Above this optimum velocity the solvent concentration greatly influences the results. For a given velocity ratio below the optimum or loading velocity Fig 7 shows the effect of the $Ma\,.\,(Gm/Lm)$ value on the $HETP$.

(2) *Effect of Hydraulic Conditions on* HETP

Figs 2 and 5 show the importance of the boil-up rate on the $(HETP/Ma)(Gm/Lm)$ value in the binary distillation system, and this effect may be explained as follows :

The initial increase in $(HETP/Ma)(Gm/Lm)$ or decrease in efficiency is attributed to a decrease in the time of contact between the liquid and vapour streams. As the boil-up rate is increased the two streams become more turbulent giving rise to an increase in mass transfer. Furthermore, as the loading velocity is approached, the effective wetted area rapidly increases because at this point the high velocity of the vapour helps to distribute the liquid more evenly across the packing cross-section. The increase in turbulence and effective wetted area more than balances the decrease in contact time and results in a lower value of $(HETP/Ma)(Gm/Lm)$. Above the loading velocity the effects of increased turbulence and wetted area are less pronounced than the decrease in time of contact and channelling effects and hence there is an increase in the $(HETP/Ma)(Gm/Lm)$ value.

Thus the variations in $HETP$ appear to be caused by a variation in the character of the liquid flow with increasing gas velocity. Below loading velocity the free path is not greatly reduced with increasing liquid rate. Above this velocity, the voids tend to fill with liquid and the gas velocity increases per unit free cross-sectional area much more quickly than the superficial gas velocity.

In the case of extractive distillation it is shown in Fig 6 that the presence of solvent influences markedly the $HETP$ value above the loading velocity. The reason for this is not clear at present, but it may be increased channelling effects, a mass transfer effect, a decreased area, or time of contact. Further work is now proceeding to investigate which factor is the most important.

(3) *Optimum Solvent Concentration*

The total height of a column required to separate a given mixture is equal to the product of the number of theoretical plates and average $HETP$. This height has been calculated for the column in the separation of methyl*cyclo*hexane and toluene from 0·10 to 0·90 mol fraction of methyl*cyclo*hexane (solvent-free basis) under total reflux conditions and with various solvent concentrations and Ug/Ug_L ratios. These results are shown in Fig 8, from which it is seen that when operating below the loading velocity the height continually decreases as the solvent concentration is increased, but above the loading velocity there is an

optimum solvent concentration of about 40 mol per cent. A minimum column height is obtained when operating at the loading velocity.

Confirmation that extractive distillation should be carried out below the loading velocity is provided by the effect of the high L/G ratios on the pressure drop through the column. The experiments showed that

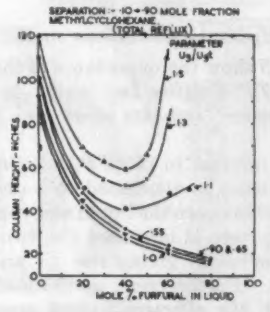

FIG 8

DETERMINATION OF OPTIMUM SOLVENT CONCENTRATIONS

below the loading velocity there is only a small increase in pressure drop due to an increase in the L/G ratio, but above the loading velocity, the pressure drop increases much more rapidly with increasing L/G ratios.

APPLICATION OF RESULTS OF *HETP* EQUATION

Equation (7) for calculating the *HETP* value at the loading velocity is limited to 21-inch height of packing, to ¼-inch Raschig rings, and to the systems methyl*cyclo*hexane–toluene and methyl*cyclo*hexane–toluene–furfural. It was therefore decided to investigate the efficiencies reported in the literature to see if the *HETP* data would correlate at the loading velocity.

The results of Deed, Schutz, and Drew,[3] Duncan, Koffolt, and Withrow,[5] Furnas and Taylor,[8] Kirschbaum,[12] and Johnson[11] have been used for this comparison. Rings of ¼-inch were chiefly used, although some information is available for other size rings and packings. The published *HETP* data has been recalculated for a column height of 8·0 ft assuming the cube root law holds. Loading velocities have been calculated by a correlation proposed by the authors[9] for Raschig rings and Berl saddles.

Equation (6) was found to give a reasonable correlation of the published results when modified as follows :

$$HETP \text{ (inches)} = 28 \,.\, Ma \,.\, Dp \,.\, (Gm/Lm) \,. \quad (8)$$

CONCLUSIONS

(1) The *HETP* is a minimum at the loading velocity for both binary and extractive distillation.

(2) Above the loading velocity the amount of solvent present in extractive distillations greatly influences the order of the $(HETP/Ma)(Gm/Lm)$ value.

(3) Below the loading velocity the $(HETP/Ma)$ (Gm/Lm) value is unaffected by the solvent concentration.

(4) In the small pilot plant, furfural has been shown to separate effectively methyl*cyclo*hexane and toluene if the column is operated below the loading velocity.

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AMENDMENTS TO IP STANDARD METHODS

CERTAIN amendments to the methods appearing in (1) "Standard Methods for Testing Petroleum and Its Products," 15th Edition, 1956, and (2) "IP Engine Test Methods for Rating Fuels," 1st Edition, 1955, have been noted. They are :

(1) *Loss on Heating Transformer and Switch Oils* (*IP* 46/55).

In para 5 (*c*) the amount of sample placed in the beaker should read 20 ml and not 30 ml.

(2) *Ignition Quality of Diesel Fuel* (*IP* 41/55 T)

Section 1 (*a*).—In the second paragraph delete the third sentence, which reads : "The ignition quality, except for the reservation in Section 1 (*d*) is, independent of the make or condition of the engine."

Note 1.—Add the following sentence : "The operator should make certain that the temperature of the sample under test in the engine is high enough to ensure homogeneity before recording any observations."

Footnote 3.—Change "the Anglo-Iranian Oil Co. Ltd." to "The British Petroleum Co. Ltd."

CORRESPONDENCE

"EXTRAPOLATED" METHODS OF RATING OILS BY ENGINE TESTS

The Editor, *Journal of the Institute of Petroleum.*

SIR,

I consider a method of rating oils by engine tests as being "extrapolated" when laboratory testing conditions differ widely from those found in normal operation of the engine or engines using the oils under test.

The unavoidable extrapolation is particularly dangerous—as are all extrapolations in laboratory work—when the duration of the test is reduced to a fraction (one-third to one-half) of the normal period of oil change when using an oil of "very good pass" quality; and when the cooling water temperature and the oil temperature clearly depart from those which are usual in normal service. This is again the case when one is assessing a specific phenomenon, *e.g.* corrosion of copper–lead bearings, which is not usually encountered in the type of engine, *i.e.* petrol engine, which is used for the test.

As examples of extrapolation procedures I would mention the following tests:

Chevrolet CRC–L4
Petter AV1
Lauson
Tests on the CLR engine

Constructive Criticism of "Extrapolated" Methods

(1) It is my opinion that extrapolation can be justified only if the specific property being measured is independent of the factors of extrapolation. Thus, in order to make the extrapolation strictly acceptable the classification of different oils by some specific property must be independent of the test conditions. It would be remarkable if this were so when considering different oils, different basic materials, and different additives. The curves indicating the variations of the specific property for the different products in terms of one or another factor of extrapolation will obviously not be related. In consequence the evaluation will be different, depending on whether the test is being run under normal or extrapolated conditions.

On the other hand, and for the same reason, it is difficult in extrapolated conditions to fix a maximum value of a specific property which will correlate with the same requirements in normal practice.

(2) In order to reduce these anomalies and difficulties, the accepted policy has generally consisted in demanding relatively severe requirements; this greatly reduces the number of oils acceptable in normal service. In these circumstances the user has his compensations, but not so the oil producer. Again, this policy may be dangerous for big consumers in times of crisis. Such would be the case with the Armed Forces, who in case of mobilization or on active service would have at their disposal only restricted supplies of oil and could not rely on reserves which have not passed the test or cannot pass it, although many of them would give satisfactory service under normal conditions of use.

(3) To sum up, with extrapolated methods:

(*a*) It is not possible to establish a rating for different oils.

(*b*) By greatly increasing the severity of the requirements it is possible to eliminate products which are considerably outside specification.

(*c*) This elimination may take place to the detriment of products which give satisfactory service in normal conditions.

(4) The "extrapolated" method has also another disadvantage, *i.e.* to make the evaluation of the specific property much more sensitive to the various factors of extrapolation, resulting in a considerable scatter in the test results. This scatter will be greater as the number of laboratories carrying out the tests increases. It follows that the variation of a test result on any particular property is sometimes considerable, *i.e.* +25 per cent of the true value.

As I was interested in this problem I asked Captain van Laer, Mechanical Transport Lecturer of the Royal Military Academy, Belgium, to analyse statistically some results of L4 tests carried out by laboratories in different countries on oils of reference REO.7, REO.7/12, and REO.8. The data were obtained either from the literature or from certain testing laboratories or from experiments carried out in our own M.T. Laboratories. In dealing with the details of this research the result obtained are confined to oil REO.7.

	Average	Mean Deviation * in percent of mean values	No. of tests required with an oil of this type to ensure that the test result lies within ±X% of the true values				
			1%	5%	10%	20%	25%
Mean piston colour rating	9·5/10	2	4	1	1	1	1
Mean overall colour rating	94·1/100	1·86	4	1	1	1	1
Loss in weight per copper–lead bearing	96 mg	22	484	20	5	2	1

* The mean deviation represents ⅘th of the total spread of readings.

If one considers the loss of weight per copper–lead bearing, the plus or minus error in one single test is of the order of 20–25 per cent. This is very large and justifies the relatively low level of requirement of the "border line pass" which is 200 mg and clearly below the requirement already lowered due to the above-mentioned desire to avoid products in current use which are definitely bad, but which might be approved

by an extrapolated method. Again this might result in the elimination of products which would be quite satisfactory in normal service.

We are far from the normal 1 per cent precision usual in laboratory work. Even if we were prepared to accept 5 per cent, then it would be necessary to carry out twenty tests on an oil of the REO.7 type. These tests should be spread over the greatest possible number of laboratories, which would result in considerable expense and a number of difficult administrative problems.

From the point of view of the average merit of piston lacquer and deposits an accuracy of 5 per cent is usually obtained in a single test with oils of the MIL-L-2104A type. The requirements of these particular properties are respectively 9/10 and 90/100. If logically one considers these figures as the lower limit of spread (in order to prevent an unsuitable oil passing the test) the real level should be about 9·4/10 for the mean piston colour rating and 94/100 for the mean overall rating. The following table shows that under these conditions the REO.7 oil obtains a border line pass and the REO.7/12 oil just fails. This conforms with the American idea for REO.7 oil but not for REO.7/12, which is graded "of high rating with respect to freedom from deposits . . ."

N.B. Apart from any criticisms of the method of extrapolation, the above statistical study allows one to improve the rating standards.

	Specification limits	Limits resulting from the statistical analysis
Mean piston rating . .	9·0/10 min	$9/10 < M < 9{\cdot}9/10$
Loss of weight per copper–lead bearing	200 mg max	$75 < P.P\ 125 < mg$

Fuel to be standardized + REO.7 oil.

Rating tests can and have been carried out on REO.7/12 oil, and the combined results of the new ratings should allow the spread of readings to be considerably reduced.

(5) The use on gasoline test engines of copper–lead bearings, which are seldom used on this type of engine, is a matter for considerable criticism and is an added danger to extrapolation.

Extrapolated Methods and their Correlation with Field Service

(1) As mentioned above, all laboratory engine tests are more or less extrapolated if only as regards the duration of the test compared with the life of an engine between two successive major overhauls. In fact, even for a test engine running under normal conditions the duration of the test rarely exceeds three or four oil change periods. Very often the duration of the test and the working conditions are decided upon in an attempt to obtain a correlation between test bed results and those obtained from normal service. The aim is nearly always to achieve identical results in both cases, *e.g.* deposits similar in quality, colour, quantity, etc.

If running conditions were absolutely identical in both cases there is still the "engine factor" to be taken into consideration; the laboratory engine does not produce deposits in the same manner as a service engine because the time factor has an importance which cannot be considered negligible.

(2) This procedure is less dangerous than the full extrapolation which I criticized previously. I wonder therefore whether correlation conceived in this manner is really logical and whether it will not sooner or later lead to confusion. In fact, why should a laboratory test form deposits on the engine components greatly resembling those obtained in normal service? Why does not one simply require the laboratory engine to produce equivalent deposits, but for a duration corresponding to the normal service life of the engine? A true correlation should be understood in this manner. It would then be necessary to determine the minimum number of oil change periods sufficient to bring out clearly the property under study in such a way that it could be measured with accuracy.

Following up this idea, the specific property of an oil always reveals itself during a test even if the running conditions are normal so long as the duration of the test covers two or three oil change periods. If under these conditions the specific property does not give measurable results, it is the test equipment which is at fault, *i.e.* it is not sensitive enough to produce the desired results. The test equipment should therefore be investigated and perhaps eventually modified or replaced by another based on a full study of the particular property to be examined. It follows naturally that the oil must continue to be tested in the engine. This idea has already been put into practice, though diffidently, with good results, as the following shows:

(1) The wear of engines attributed to the lubricant is perhaps the most difficult property to assess and to measure quantitatively. A certain number of actual tests have been designed to look into this question, but without any substantially practical conclusions. In the U.S.A. during the past few years a more sensitive method has been considered in which cylinder and ring wear has been measured by using radio-active piston rings. The first results have been definitely favourable.

(2) The phenomenon of corrosion of engine components and the influence of the oil on this is another difficult problem. However, after metallurgical examination of the corrosion of the various parts of an engine Axel Bodey, of the "Motoren Werke" of Mannheim, established that the electro-chemical reactivity of the oil played a predominant role, and from this he deduced an original method of measurement far more sensitive and accurate than the classical determinations of the variation in size and weight.

E. Sibenaler,
Professeur l'Ecole Royale Militaire de Belgique.
Brussels.

FAULTING AND OIL ACCUMULATION

The Editor, *Journal of the Institute of Petroleum.*

SIR,

The paper under this title by G. D. Hobson (*J. Inst. Petrol.*, 1956, **42**, 23) is timely, not only because it shows that the *Journal* is still prepared to devote some space to geological questions but also because the current search for oil in Australia is very largely dependent on a proper understanding of the process of migration.

Dr Hobson, rightly, inclines to veer away from the "primary" and "secondary" terminology used by Professor Illing, as "primary" migration may be so restricted in movement as to constitute an abuse of the modern interpretation of the word "migration." A family which moved, say from Wimbledon to Putney, would not be described as migrants in modern English usage.

I feel, however, that Dr Hobson's approach to the problem of the movement of petroleum along faults would be much more valuable had he dealt with the matter from the dynamic point of view instead of an almost entirely static one.

During long experience in the field, of which a large part has been spent in attempts to solve (sometimes with success) the vagaries of "pools" of migrated oil, only in a very few cases have I been able to assume (and much less to prove) more than a mere trickle of oil along static fault planes. Within my experience, substantial flows have occurred only when the fault is active. Specifically, I have never been able to assume or prove—nor, I believe, has any other geologist on field evidence—that "step-ladder" migration, of the type illustrated in Fig 6 *c* of Dr Hobson's paper, has occurred over a measurable distance in nature.

A most important aspect of the migration of petroleum (not touched upon in the paper) is migration without faulting or fault zones. This, I assume, in the Illing terminology, would be labelled "tertiary." This occurs when the oil, already accumulated in a "pool," reaches the surface through passage along active fault planes, or by "squeezing" of the underlying structure, or by erosion of the cover-rock, and is then transported by water-borne particles some distance away from the seep, where they settle to form a stratum of oil-impregnated mud. I have observed this process in action in many parts of South America. It is often possible to squeeze oil out of such muds by hand.

When such muds are compacted the oil is forced into the more permiable lenses within the deposit—and, again, such segregation may be observed in the field in mud banks of which a section has been laid bare by erosion. It is notable that such lenticular masses in the "La Puerta" series were utilized as a source of oil from horizons overlying the main "pool" at El Mene de Buchivacoa in Venezuela, and it is interesting to note that the chemical and physical characteristics of the oil produced varied in a manner which could be correlated with the amount and intensity of migration.

Had this rather obvious fact (which I pointed out in reports to the company involved) been accepted as correct, and had its practical implications been realized at the time, the labour and funds inverted in an attempt to develop the evanescent media offshoot of El Mene, and in deep drilling on the El Mene perimeter, might have been employed to much better purpose.

The search for oil in Australia is now passing through a similar phase at Rough Range (Western Australia), Wilkatana (South Australia), and Woodside (Victoria), at all of which the characteristics of the samples of oil recovered and analysed point to long-distance migration and micro-filtration.

LAUNCELOT OWEN (Fellow)

Sydney, N.S.W.,
28 *March* 1956.

TEMPERATURE DEPENDENCE OF THE VISCOSITY OF LIQUIDS

The Editor, *Journal of the Institute of Petroleum.*

SIR,

In your February issue, Cornelissen and Waterman proposed the use of $\log (\nu_{20}/\nu_{70})$ as an index of the viscosity–temperature relation of liquids, especially lubricating oils. Here ν_{20} and ν_{70} are the kinematic viscosities in absolute units at 20° and 70° C, respectively.

This index is derived from the equation :

$$\log \nu = (A/T^x) + B \quad . \quad . \quad . \quad (1)$$

previously introduced by the same authors as indicative of the viscosity–temperature relationship. Equation (1) reduces to the form :

$$\log (\nu_a/\nu_b) = A[(1/T_a)^x - (1/T_b)^x] \quad . \quad (2)$$

If the exponent x has a common value for a group of liquids whose viscosity is known at temperatures T_a and T_b, then

$$\log (\nu_a/\nu_b) = kA \quad . \quad . \quad . \quad . \quad (3)$$

and $\log (\nu_a/\nu_b)$ provides a relative measure of A, the viscosity temperature slope.

As Cornelissen and Waterman point out, the utility of this index is limited to comparing liquids having closely similar x values. Cornelissen and Waterman

also provide data on twenty-five lubricating oils which range from 3·0 to 4·2 in x, the median being 3·5. This variation seems so great that its effects demand evaluation.

Upon calculation I have found that the temperature interval, $(1/T_{20})^x - (1/T_{70})^x$, is $0{\cdot}1497 \times 10^{-8}$ when $x = 3$, and drops to $0{\cdot}2736 \times 10^{-11}$ when $x = 4$. The change is five-hundredfold. Hence the parameter, $\log(\nu_{20}/\nu_{70})$, seems unsuited for rating the twenty-five oils studied as a single group, and its utility under more limited circumstances is open to question. It is, however, possible that $\log(\nu_a/\nu_b)$ is actually a better measure than the foregoing analysis indicates.

Equation (1) represents an attempt to approximate the general equation :

$$\log \nu = Af(T) + B \quad . \quad . \quad . \quad (4)$$

by the use of only three independent constants. Perhaps if the expression for $f(T)$ were carried into a larger number of terms, analysis would show a higher order of correlation between $\log(\nu_a/\nu_b)$ and A.

It is not necessary to determine $f(T)$ to check this possibility. Since

$$\log(\nu_a/\nu_b) = A[f(T_a) - f(T_b)]$$

and

$$\log(\nu_c/\nu_b) = A[f(T_c) - f(T_b)]$$

$$\frac{\log(\nu_a/\nu_b)}{\log(\nu_c/\nu_b)} = K \quad . \quad . \quad . \quad . \quad (5)$$

for all oils having the same $f(T)$.

Cornelissen and Waterman determined the values of x in equation (1) by the use of viscosity data at 20°, 40°, and 70° C. If upon substituting their data in equation (5) they were to obtain substantially the same value of K for all oils, they would seem to establish the utility of $\log(\nu_a/\nu_b)$ as an index for relating viscosity–temperature properties. In this event equation (1) becomes superfluous and possibly misleading in rating liquids.

Very truly yours,

W. C. Winning (Fellow)

New York,
19 *April* 1956.

OBITUARY

STANLEY HERBERT CHAPMAN, M.A., 1875–1956

With the death of Stanley Herbert Chapman on 23 March 1956, the Institute loses one of its oldest members and the petroleum industry one of its pioneers in the realm of oil exploration and development.

His first association with the petroleum industry was in 1901, when he was apprenticed to Messrs Bergheim and MacGarvey, of Glinik Maryampolski, West Galicia, who were then operating producing wells in that area and also manufacturing drilling equipment. From Galicia, Stanley Chapman travelled to Roumania, on to Texas to work on rotary drilling, and back to Europe for a period in Russia. In 1906 he went to Mexico to work on the new oilfields of Messrs S. Pearson & Son Ltd. in Tehaunepec and eventually became superintendent of operations.

After about six years he moved to the Dutch East Indies and North Borneo as field manager for the Shanghai-Langkat Company, and remained there until he joined the allied forces in the first world war. At the end of that war he joined the D'Arcy Exploration Company Ltd., subsidiary of the then Anglo-Persian Oil Company Ltd., and spent the next five years on oil exploration in such places as Egypt, Patagonia, and the Argentine. Following a year in London, he went to Iraq in 1926 on oil exploration work for the Turkish Petroleum Company Ltd. (now Iraq Petroleum Company Ltd.), and remained in the service of that Company until 1946, apart from a period during the second world war when he was seconded for work in the Government service on matters pertaining to petroleum.

Stanley Chapman was as versatile as the above brief outline of his career indicates. He had a charming personality, and those who can claim his friendship will have pleasant memories of him.

He was one of those who agreed to become a member of the Institute of Petroleum Technologists prior to its formation in 1913. In 1939 he was elected to the Fellowship.

G. S.

SPECIAL ITEMS

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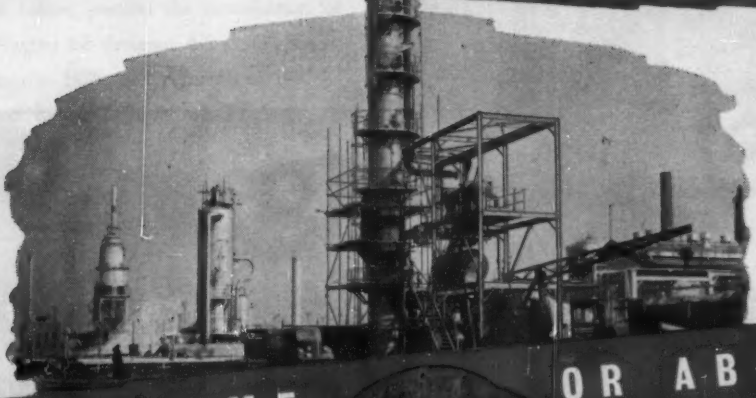

- A Platformate Splitter-column and ancillary plant at the B.P. Kent Oil Refinery, Isle of Grain.

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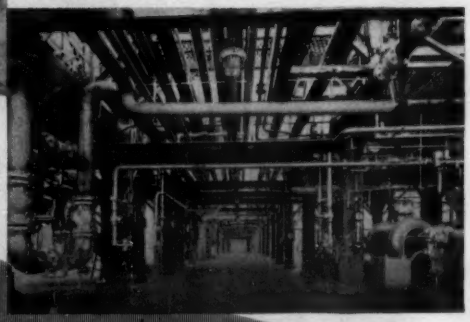
General view of crude, visbreaking, desulphurising, recovery and stabilisation units.

Graphic type panels are installed on both sides of control room with operator desk panels in centre. Crude and visbreaker unit panel is illustrated.

General view of Refinery with Mantova in background.



Over-head steam, water, oil and gas lines substantially supported and conveniently located for distribution between the units.

The Refinery was designed by the Koch Engineering Company, Wichita, Kansas, U.S.A.

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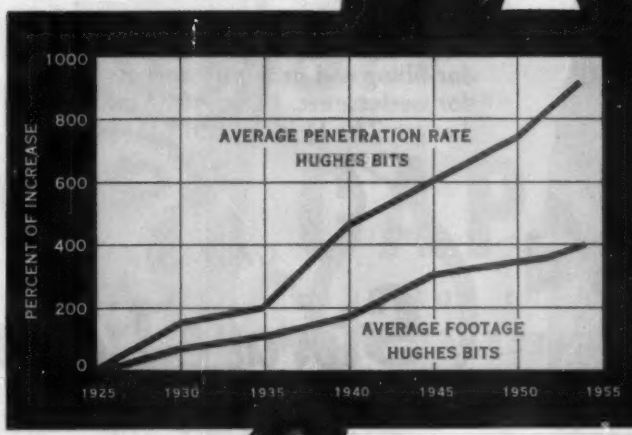

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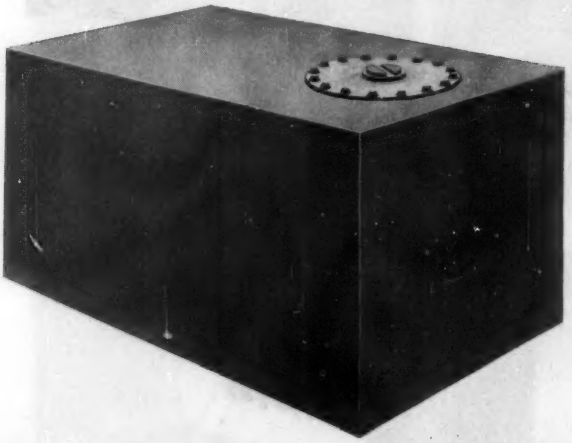

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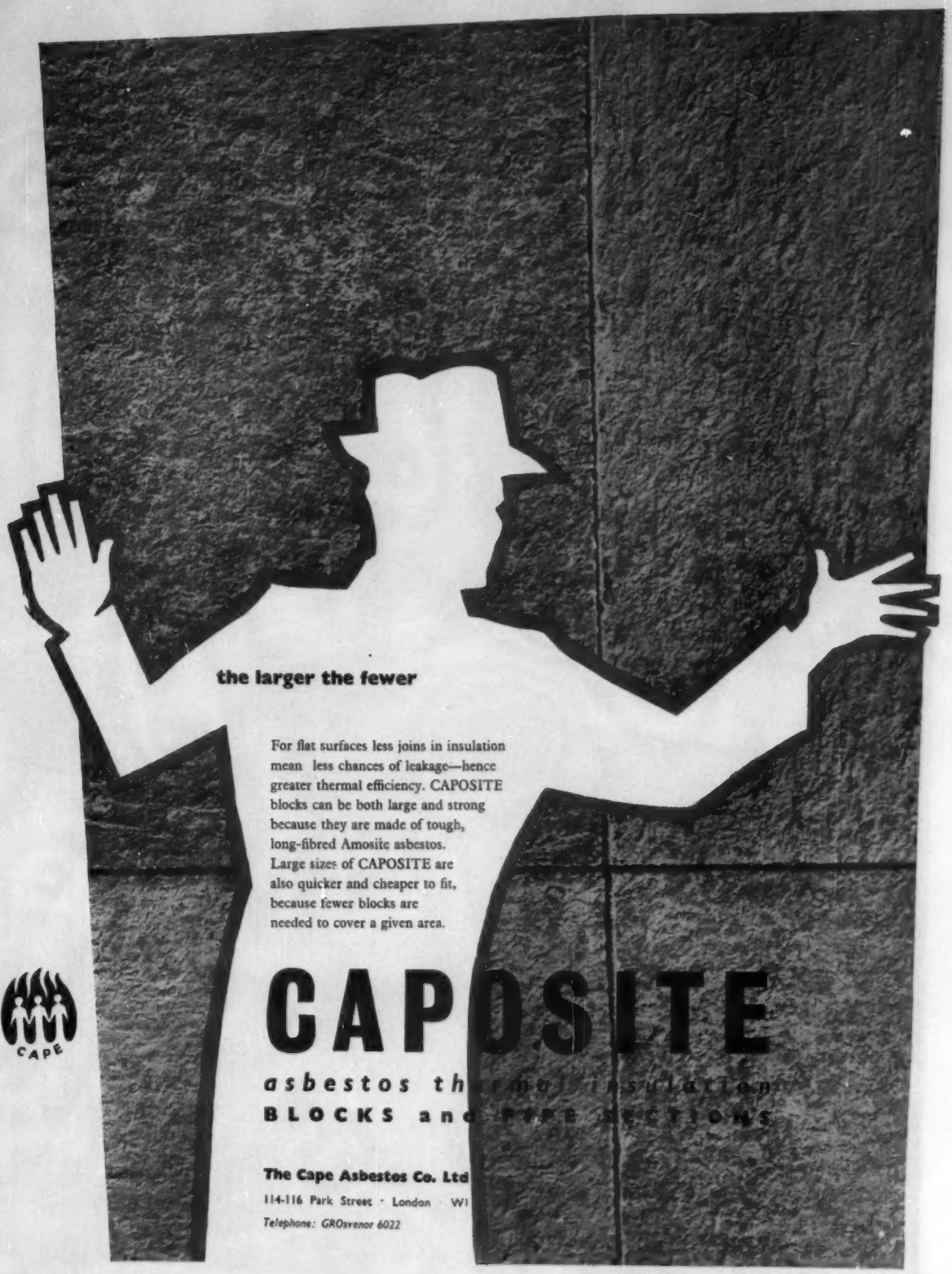
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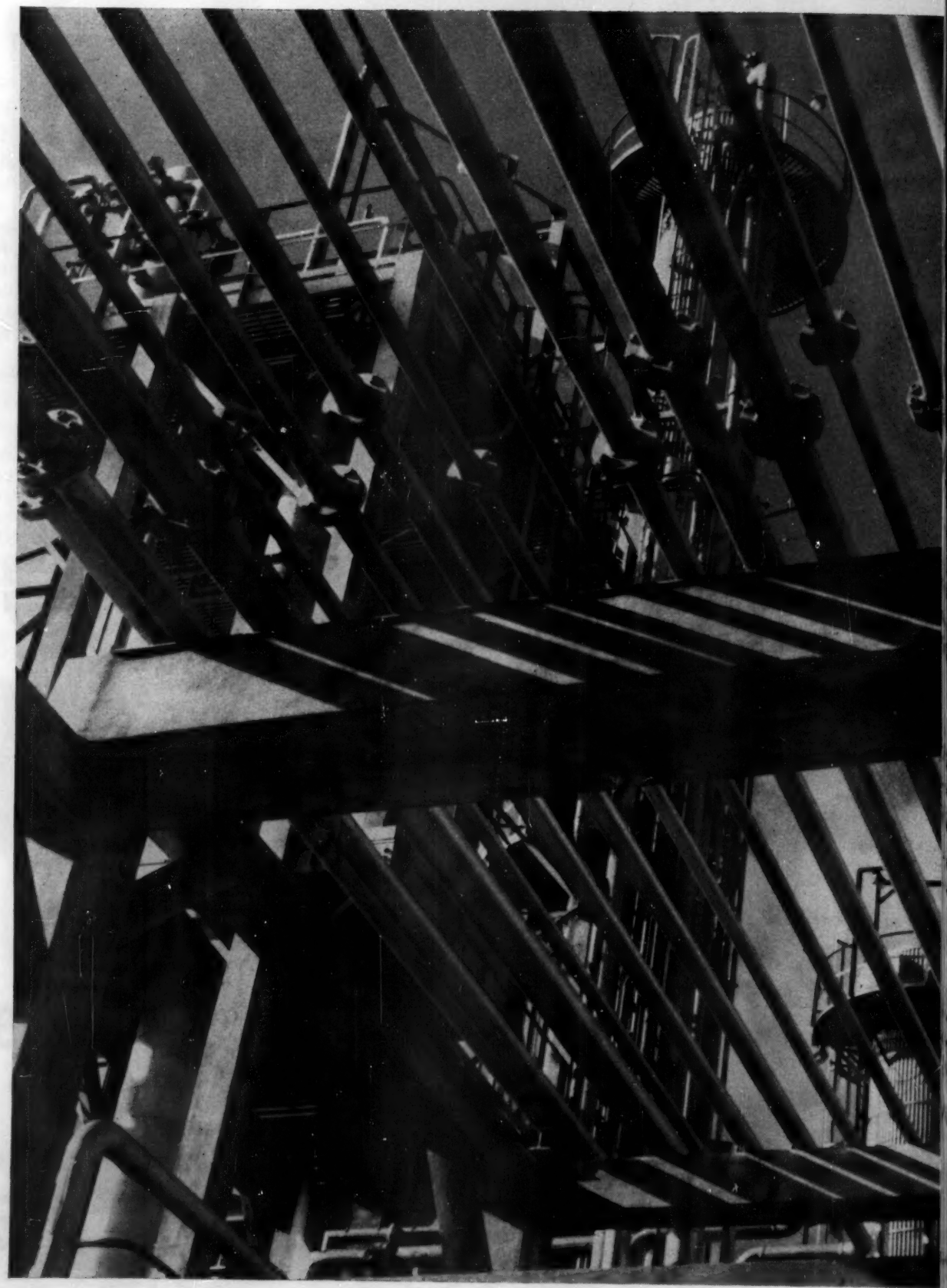

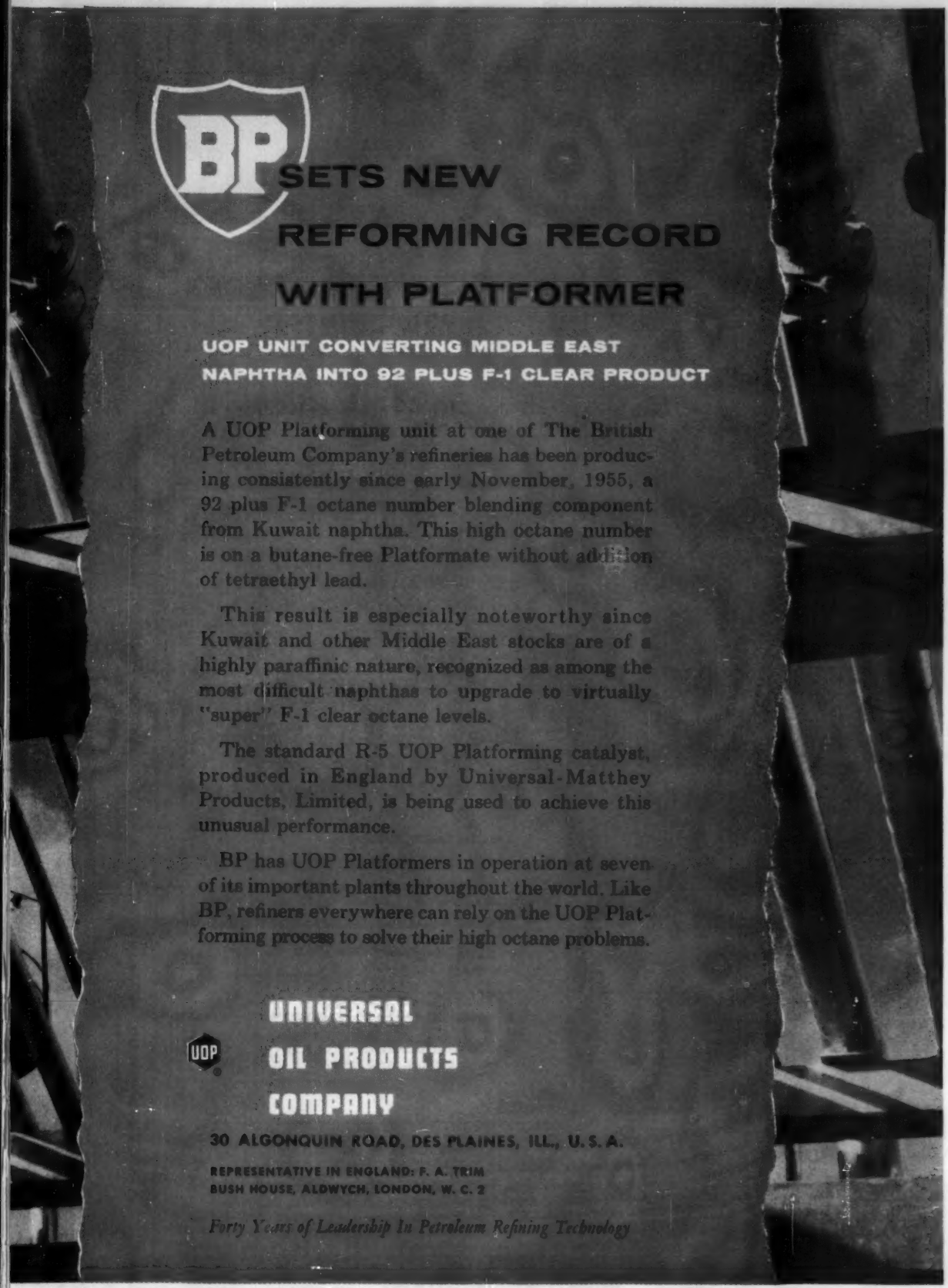
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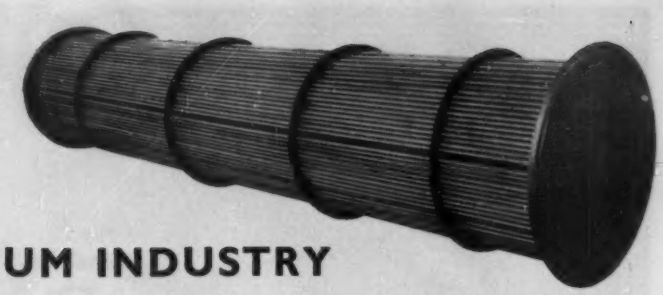

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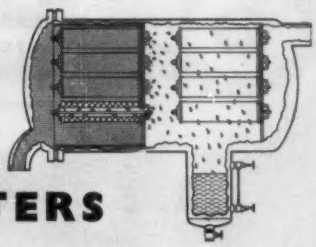

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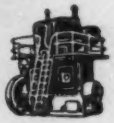

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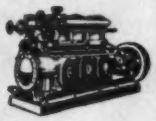

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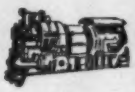

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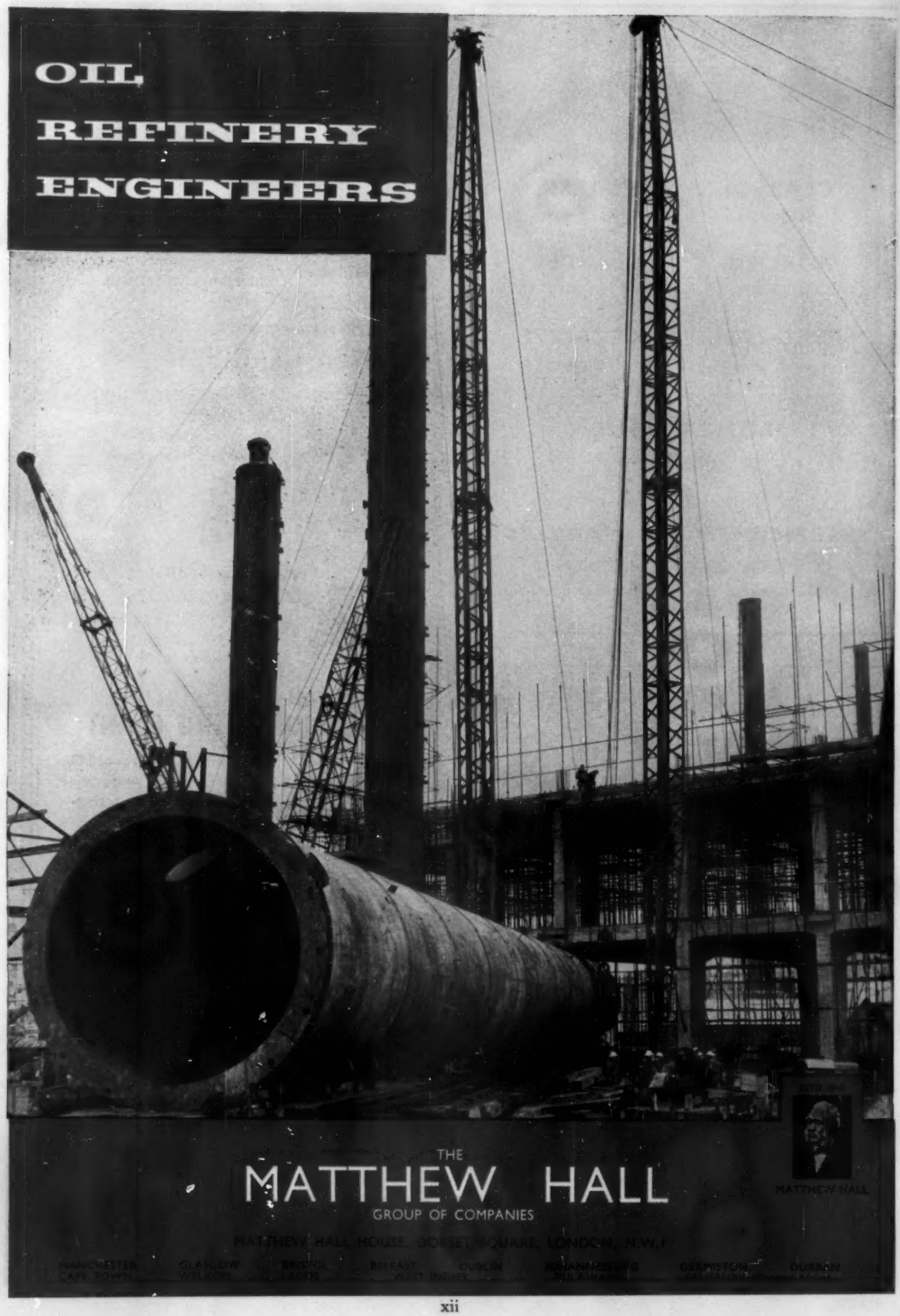
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